US005633935A

United States Patent [19]

Kanamori et al.

[11] Patent Number: 5,633,935

[45] Date of Patent: May 27, 1997

[54] **STEREO ULTRADIRECTIONAL MICROPHONE APPARATUS**

[75] Inventors: **Takeo Kanamori**, Hirakata; **Junichi Tagawa**, Osaka; **Satoru Ibaraki**, Osaka; **Hiroki Furukawa**, Osaka; **Kiminori Ono**, Katano, all of Japan

[73] Assignee: **Matsushita Electric Industrial Co., Ltd.**, Japan

[21] Appl. No.: **225,625**

[22] Filed: **Apr. 11, 1994**

[30] **Foreign Application Priority Data**

Apr. 13, 1993 [JP] Japan 5-085952
Oct. 14, 1993 [JP] Japan 5-256776

[51] **Int. Cl.**^{6} **H04R 5/00**

[52] **U.S. Cl.** **381/26**; 381/92

[58] **Field of Search** 381/26, 92, 1, 381/17, 111, 112, 113

[56] **References Cited**

U.S. PATENT DOCUMENTS

3,715,500	2/1973	Sessler et al. .	
3,793,489	2/1974	Sank .	
4,066,842	1/1978	Allen .	
4,742,548	5/1988	Sessler et al.	381/92
4,893,342	1/1990	Cooper et al.	381/26
5,107,467	4/1992	Jorgensen et al.	367/116

FOREIGN PATENT DOCUMENTS

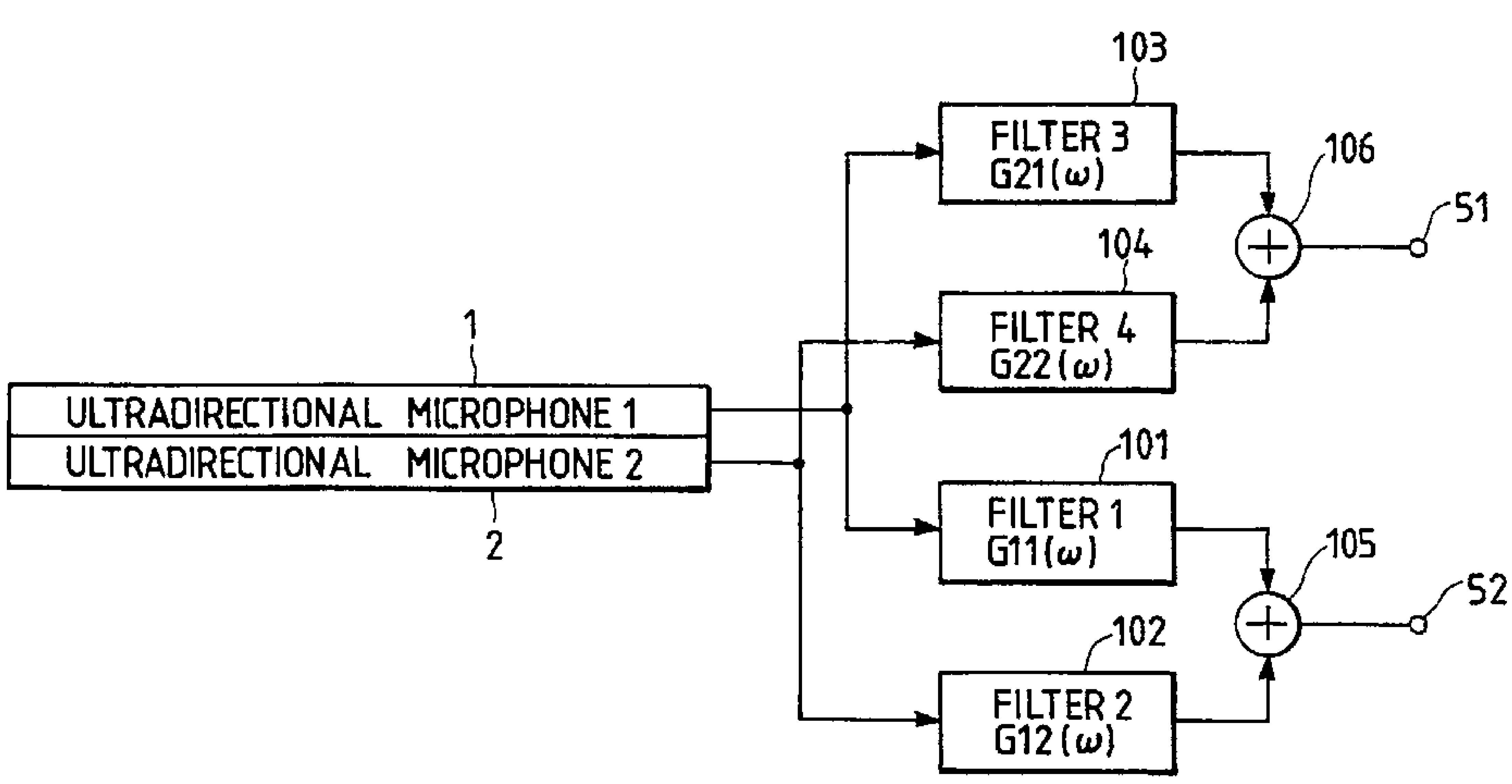
2918831	11/1980	Germany .
3-131199	6/1991	Japan .
4-144399	5/1992	Japan .
90 00851	1/1990	WIPO .

Primary Examiner—Curtis Kuntz
Assistant Examiner—Vivian Chang
Attorney, Agent, or Firm—Rossi & Associates

[57] **ABSTRACT**

A stereo ultradirectional microphone apparatus for detecting a sound to produce stereo sound signals, comprises: first and second ultradirectional microphones arranged side by side with a given distance in parallel for converting a sound into first and second sound signals respectively, first and second delays for delaying an output of the first and second microphones by a delay time τ respectively, and first and second subtractors for subtracting for subtraction between the first sound signal and an output of the second delay and subtracting for subtraction between the second sound signal and an output of the first delay. The delay time τ corresponds to a difference between the timings of a sound from a sound source in a direction making a clockwise angel θ from the front where a dead angel should be made. The subtraction provides the dead angle. Similarly, a dead angle on the side is also made to obtain a stereo characteristic. The directivity in the frequency characteristic of microphone is equalized to cancel the sensitivity in the dead angle. A stereo apparatus for forming the dead angles with two set of two filters having respective transfer characteristics determined by measurement and an adder is also disclosed.

6 Claims, 11 Drawing Sheets



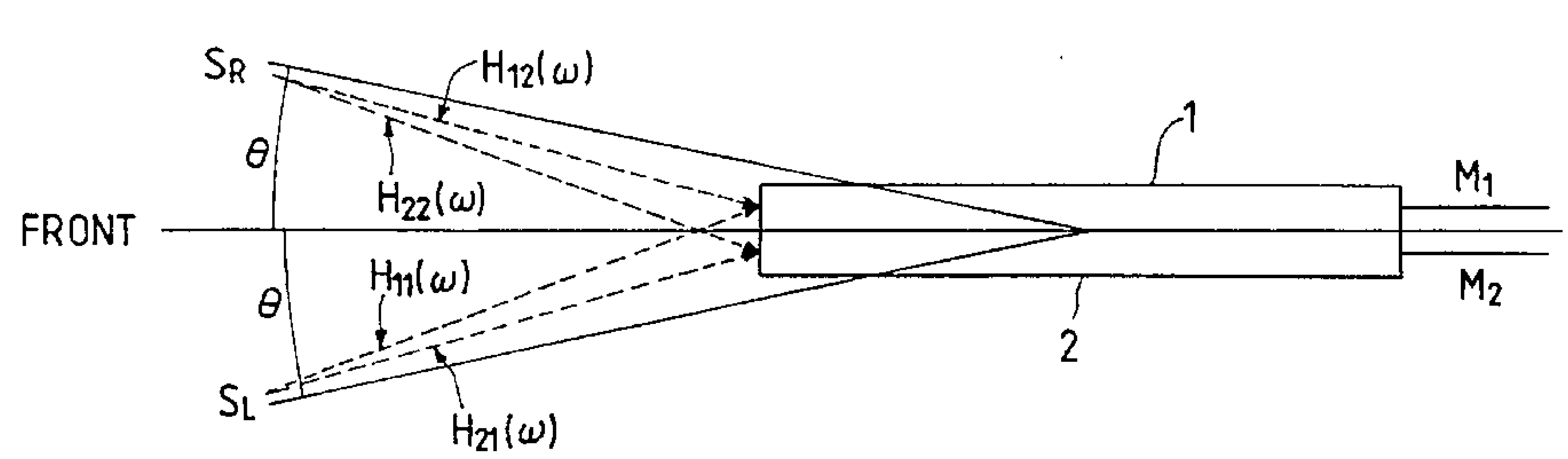


FIG. 1

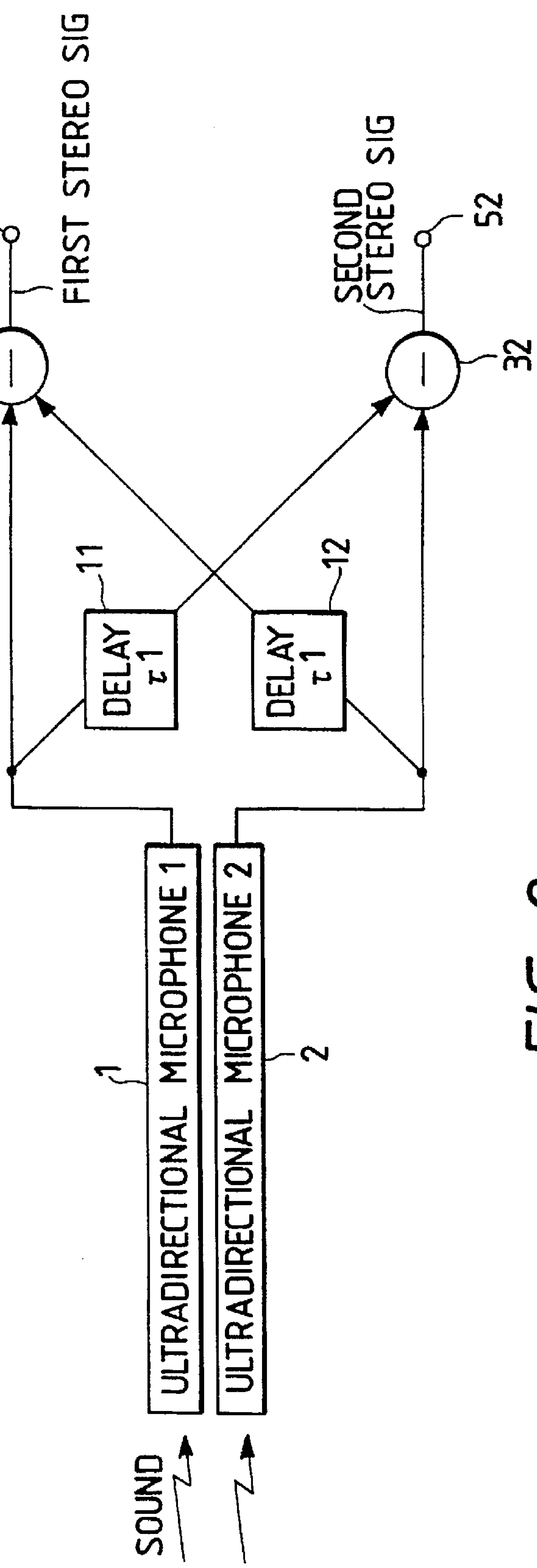

SOUND
ULTRADIRECTIONAL MICROPHONE 1
ULTRADIRECTIONAL MICROPHONE 2
1
2
DELAY τ1
DELAY τ1
11
12
31
32
51
52
FIRST STEREO SIG
SECOND STEREO SIG

FIG. 2

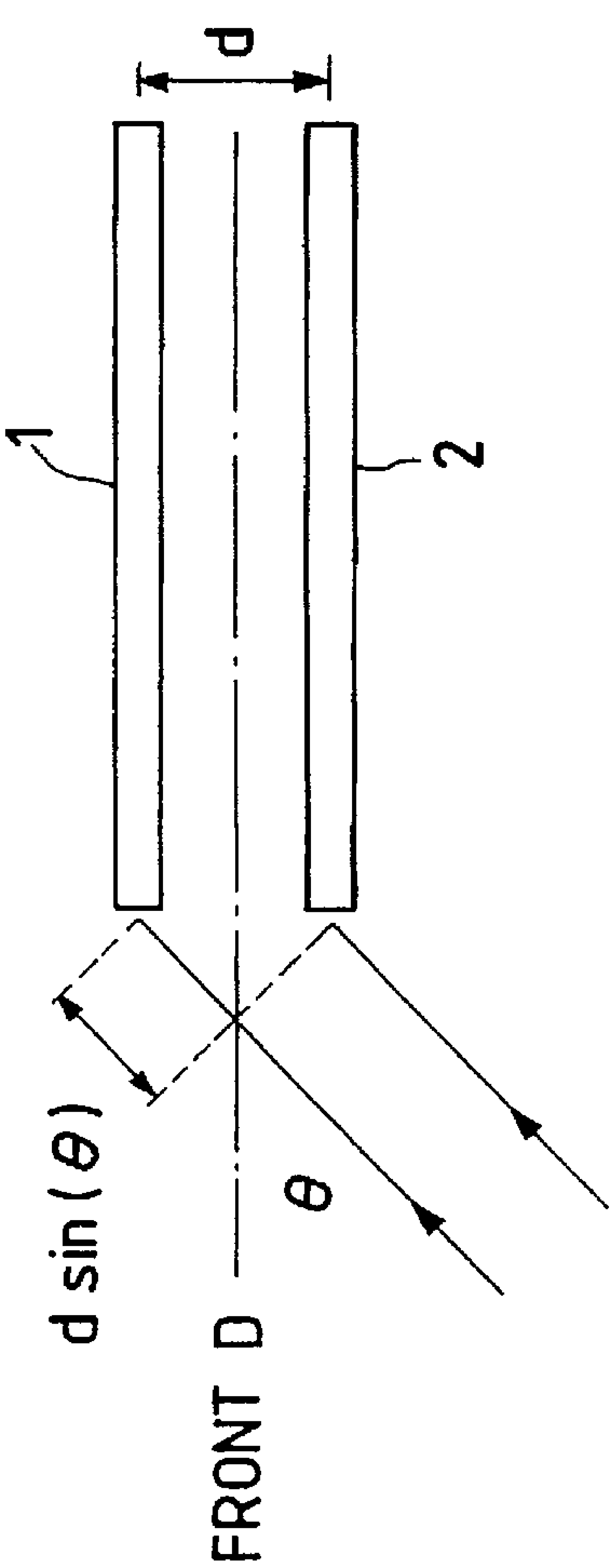

d
1
2
d sin (θ)
θ
FRONT D

FIG. 3A

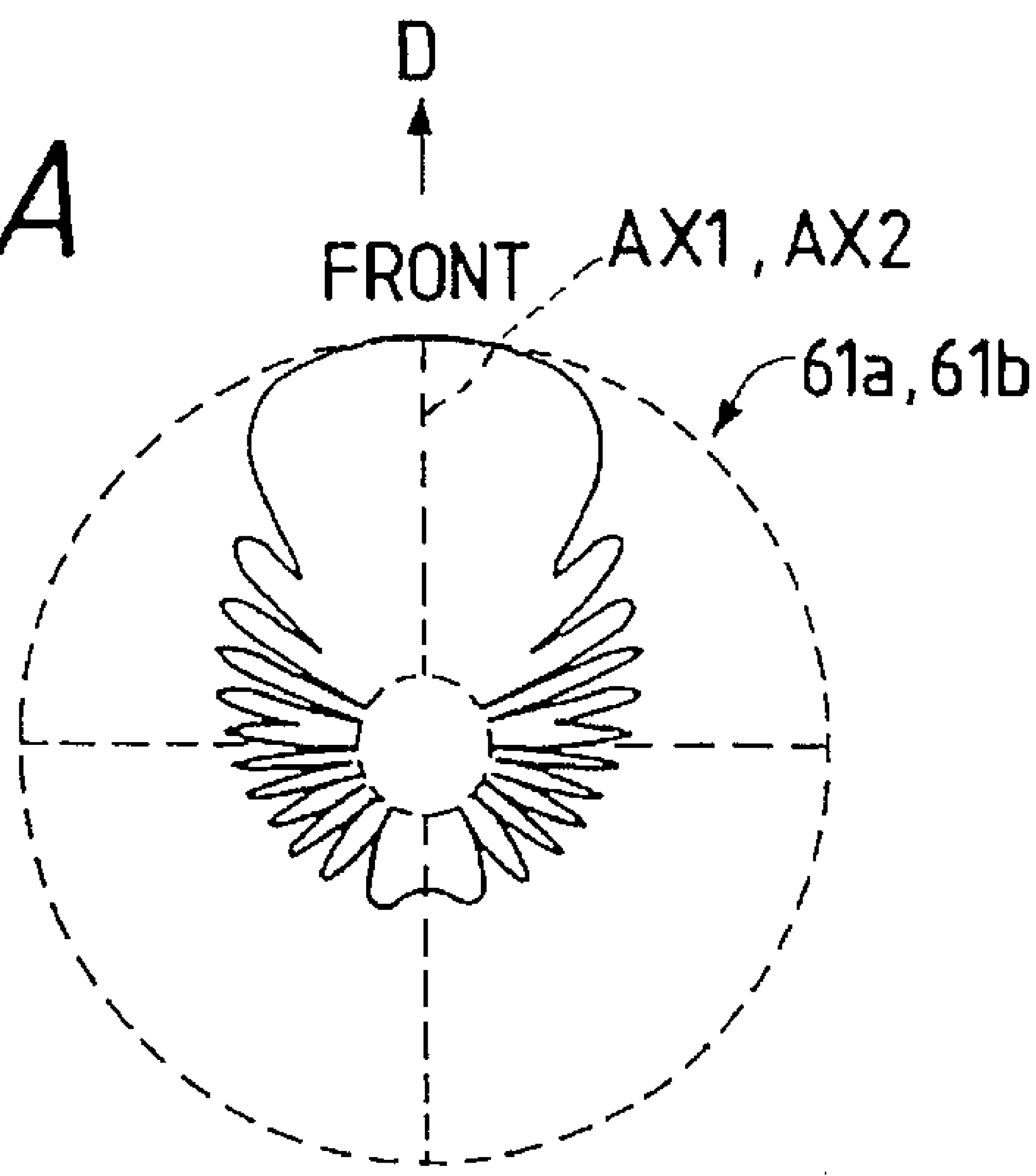


FIG. 3B

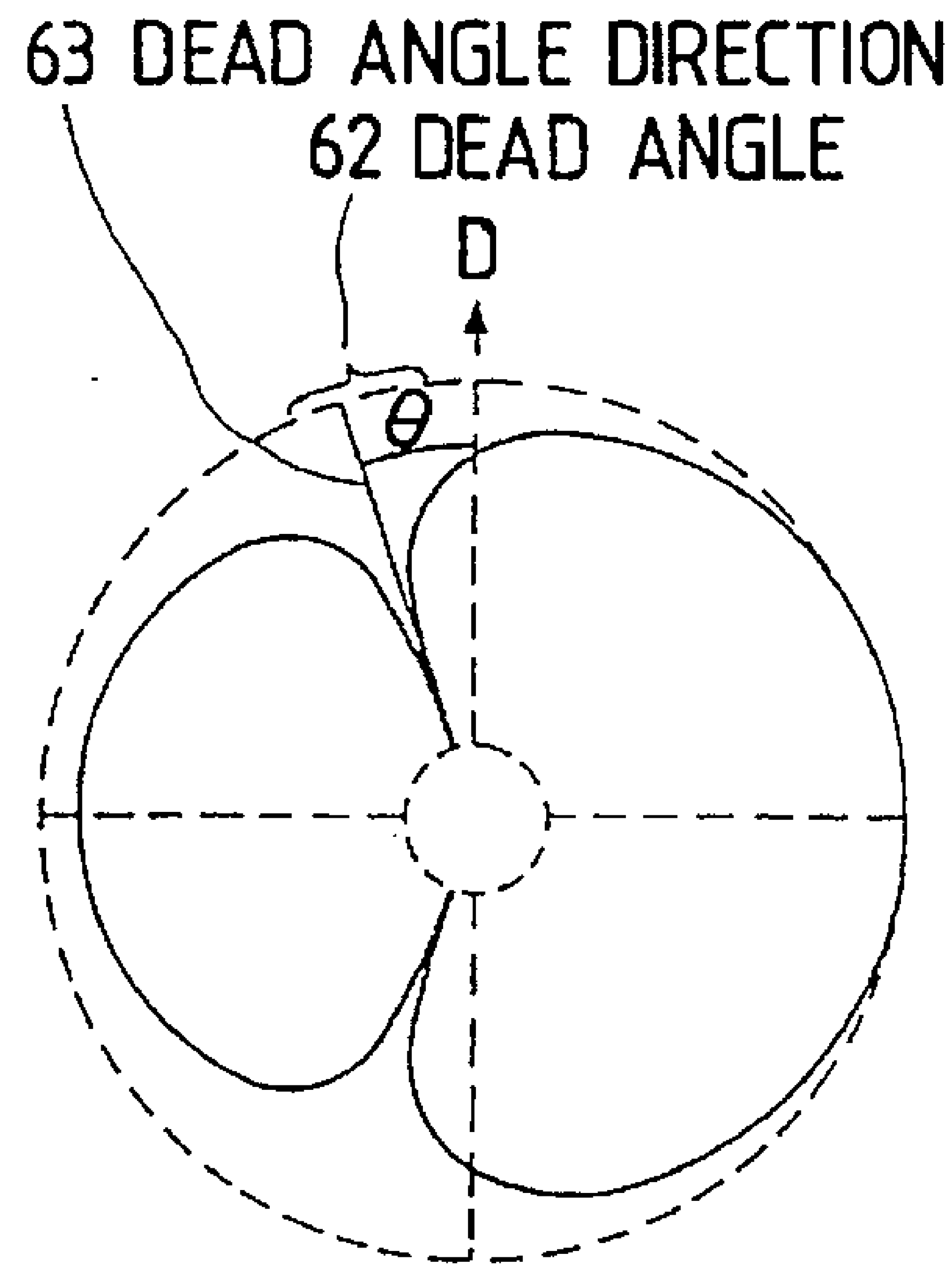


FIG. 3C

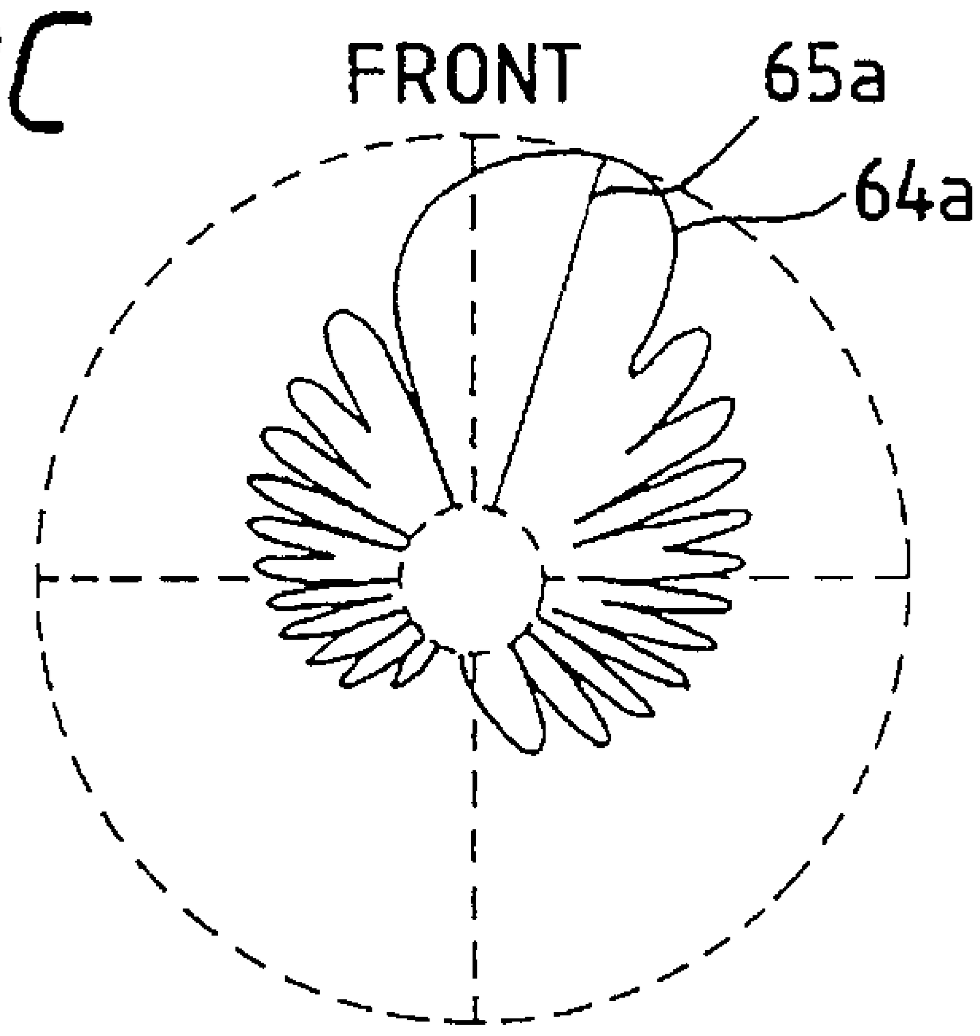


FIG. 3D

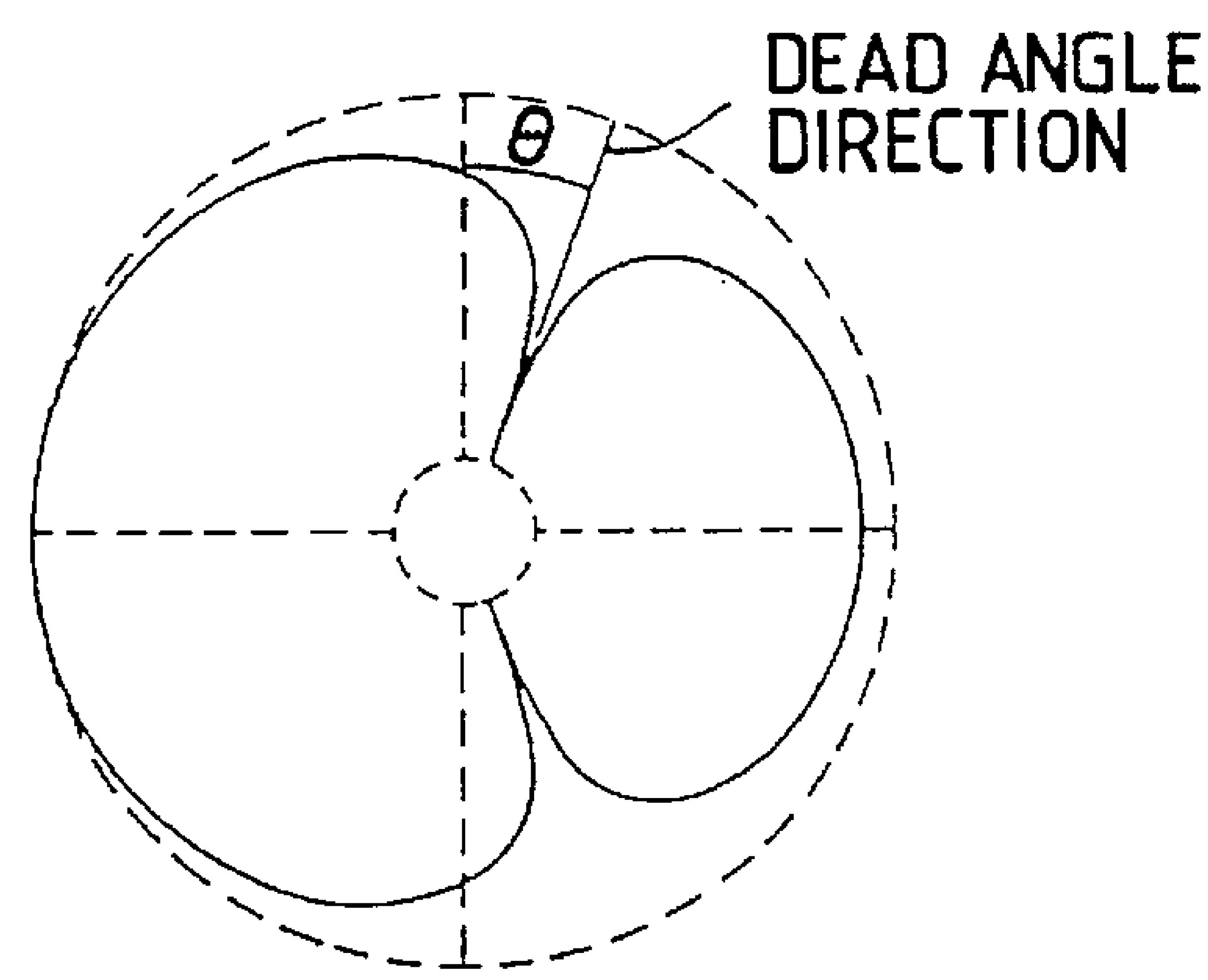


FIG. 3E

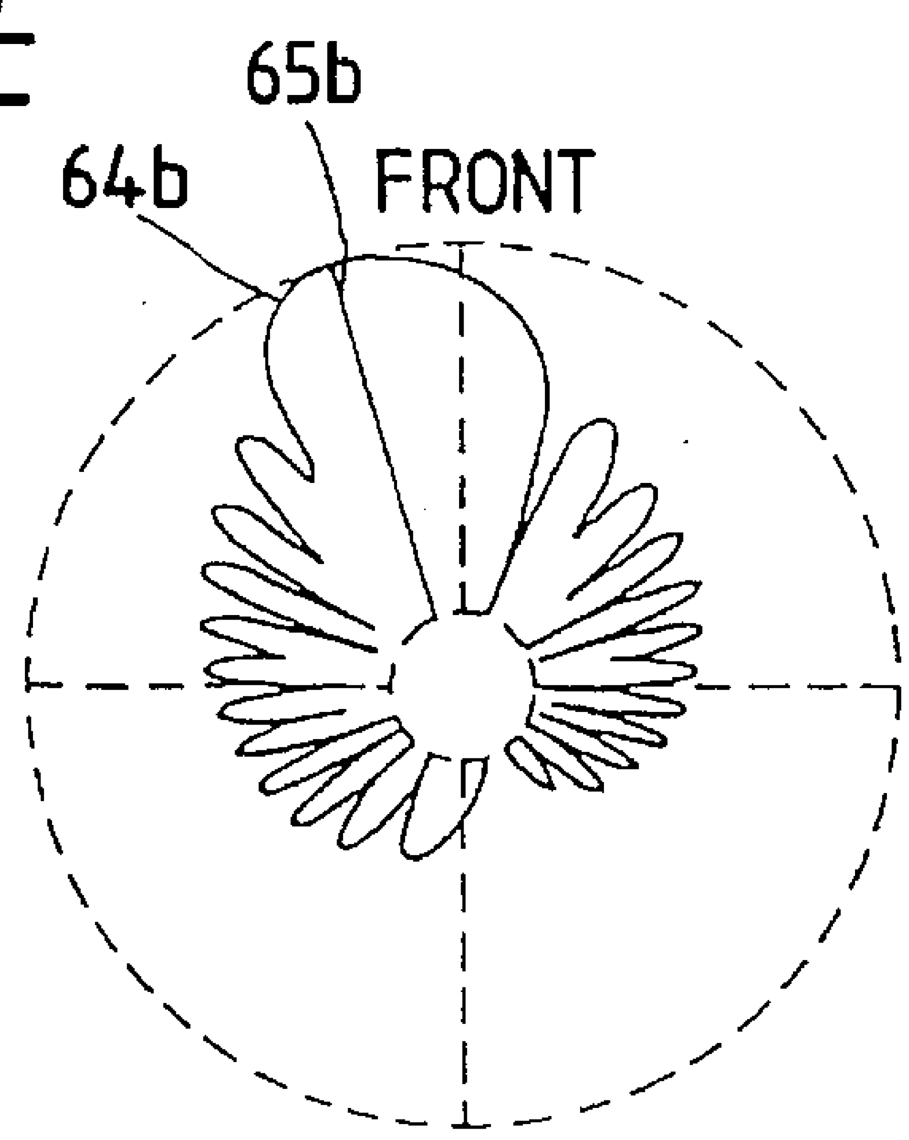


FIG. 4A

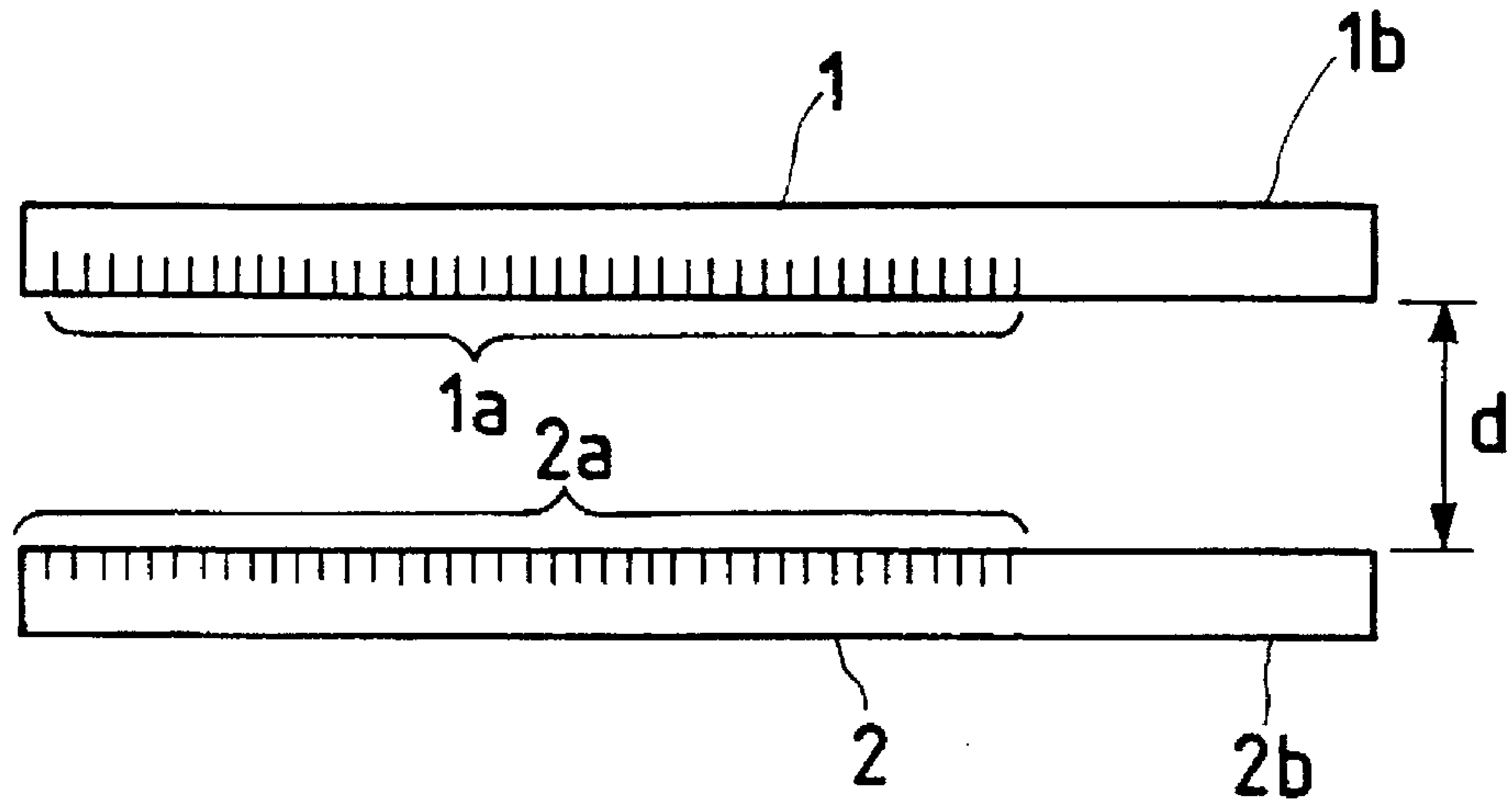

1
1b
1a
2a
d
2
2b

FIG. 4B

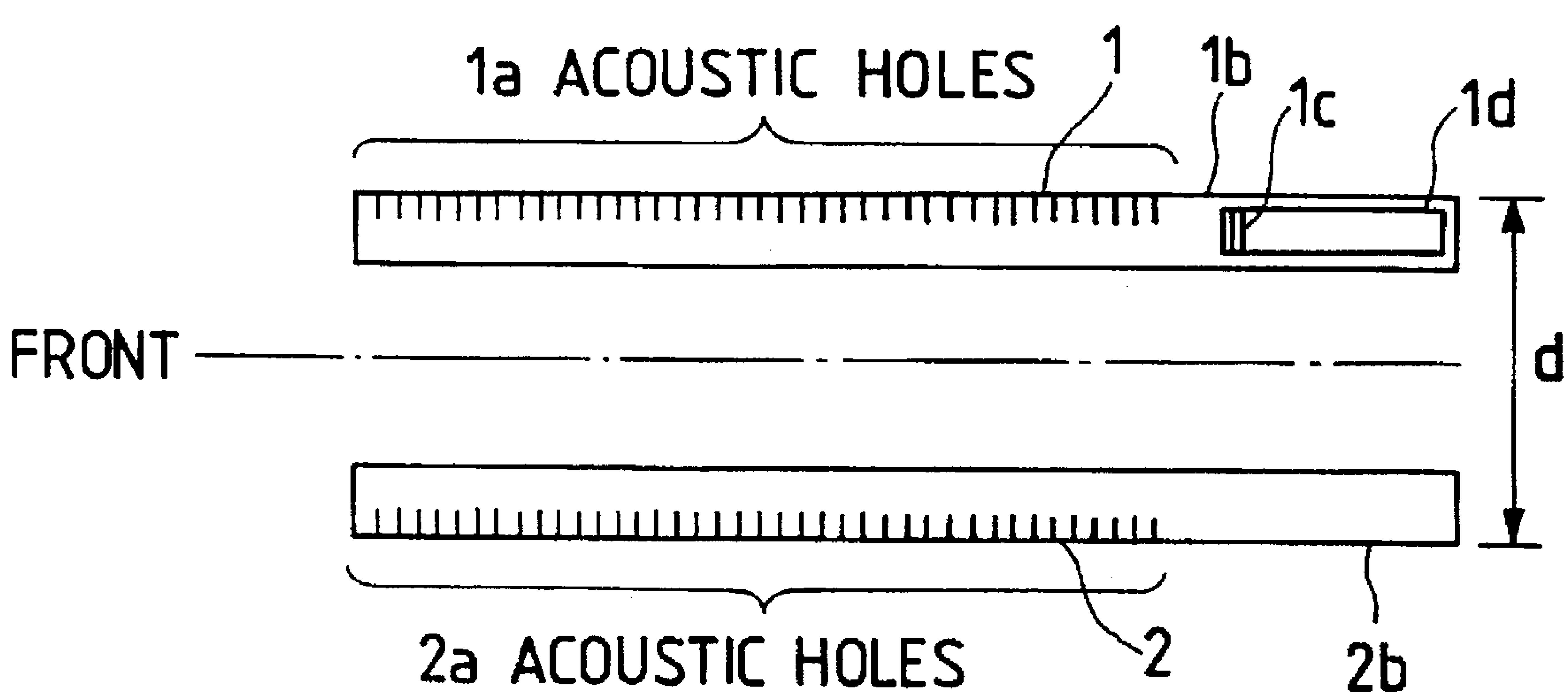

1a ACOUSTIC HOLES
1
1b
1c
1d
FRONT
d
2a ACOUSTIC HOLES
2
2b

FIG. 4C

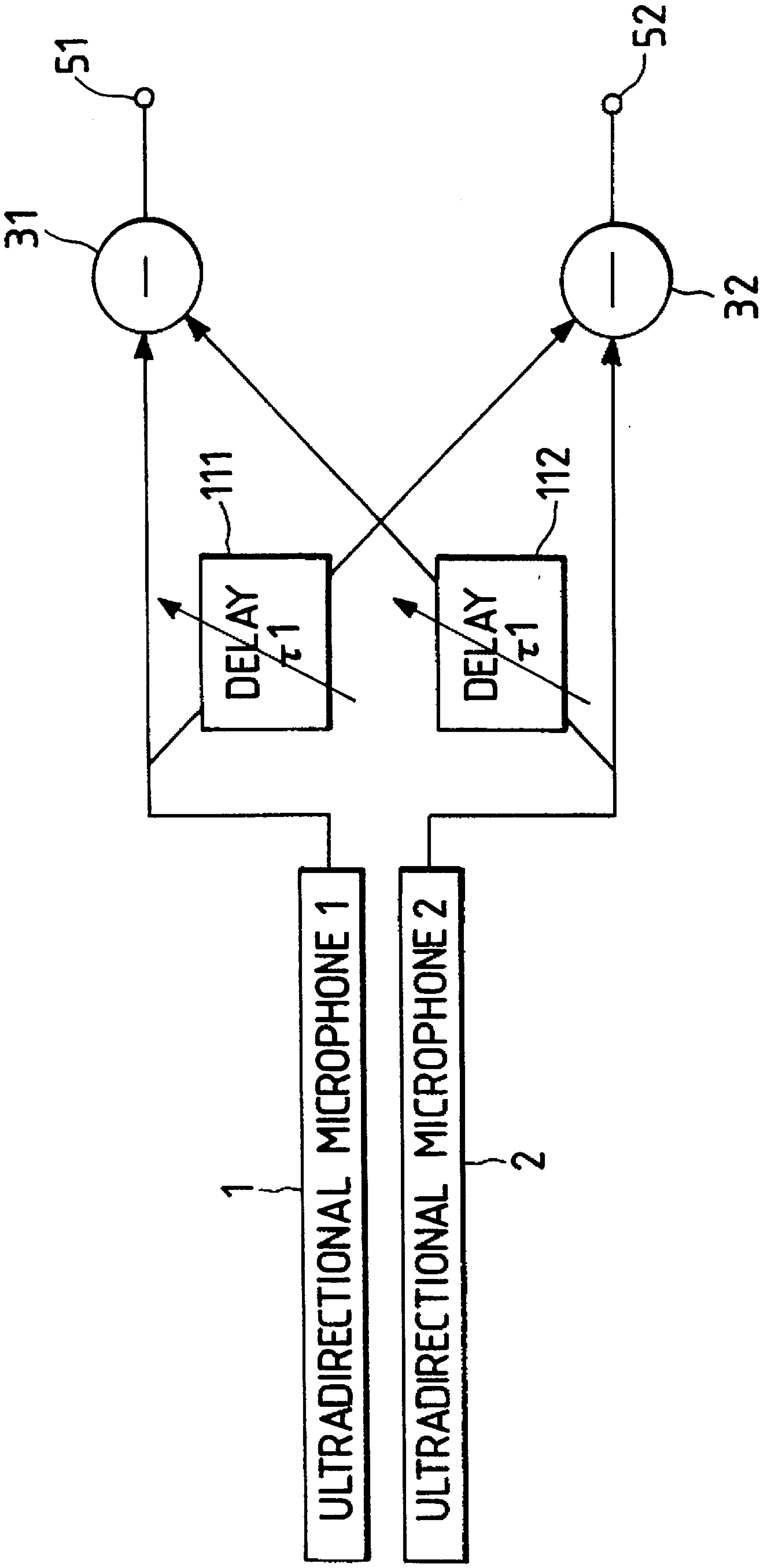

51
52
31
32
111
112
DELAY
τ1
DELAY
τ1
ULTRADIRECTIONAL MICROPHONE 1
ULTRADIRECTIONAL MICROPHONE 2
1
2

FIG. 4D

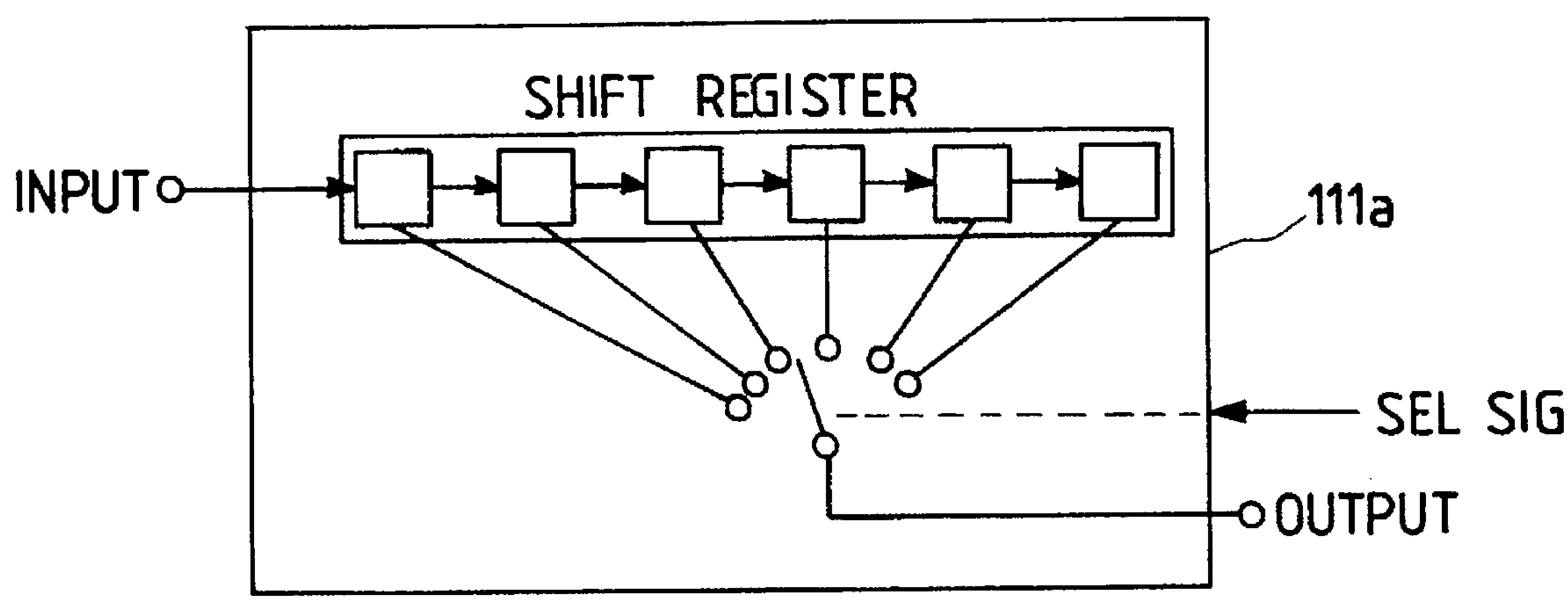

SHIFT REGISTER
INPUT
111a
SEL SIG
OUTPUT

FIG. 4E

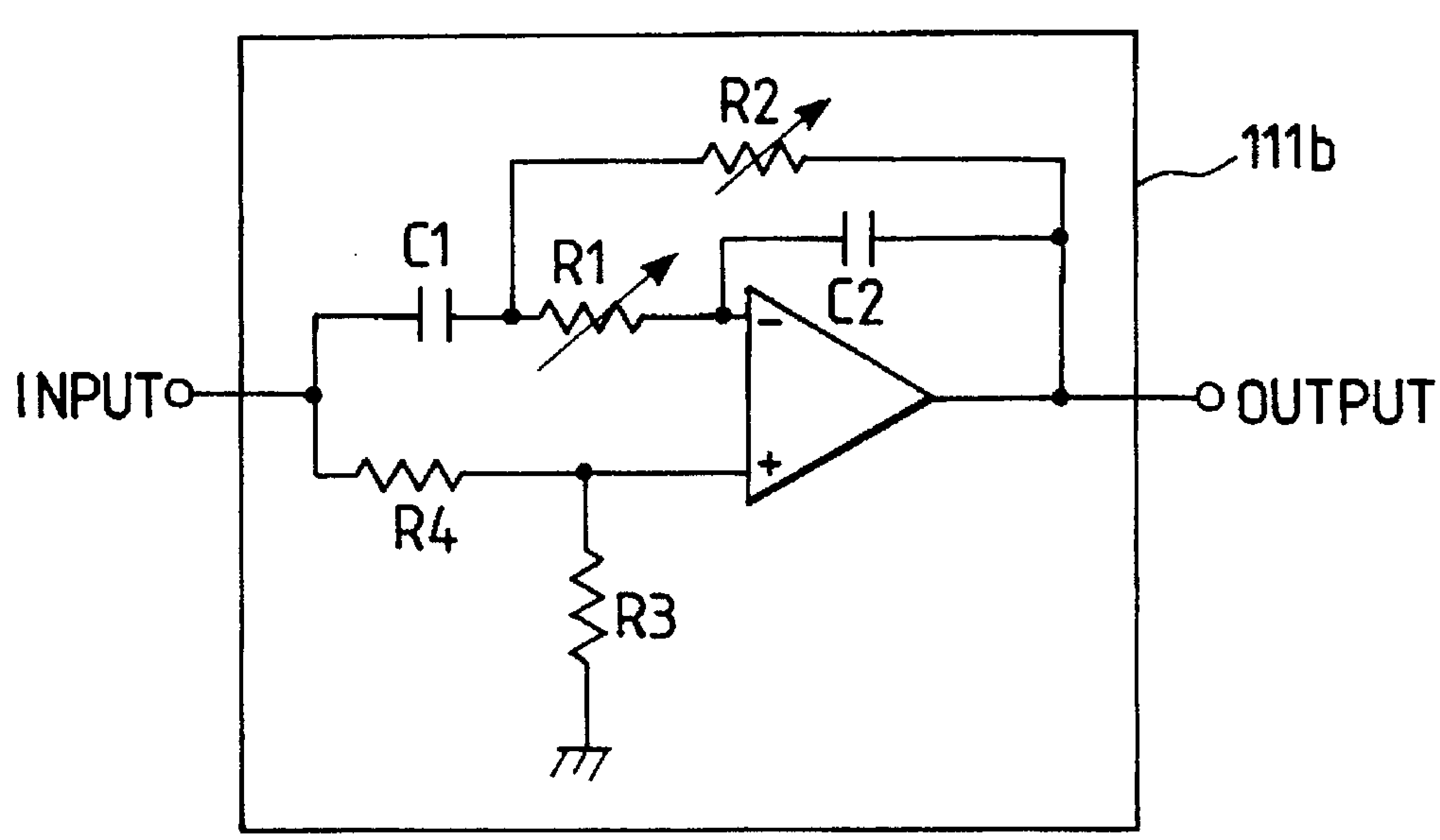

R2
111b
C1
R1
C2
INPUT
OUTPUT
R4
R3

FIG. 5A

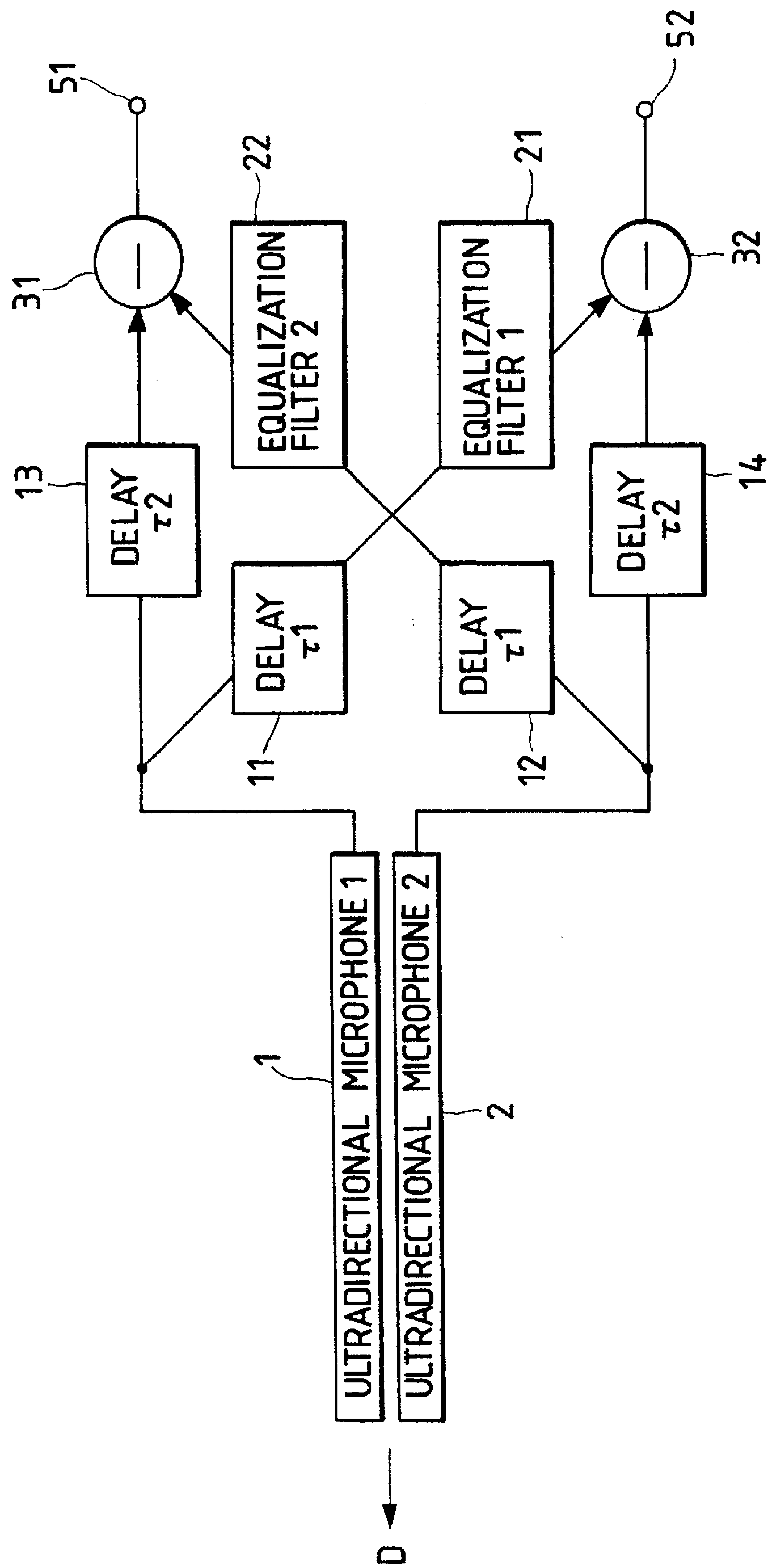

ULTRADIRECTIONAL MICROPHONE 1
ULTRADIRECTIONAL MICROPHONE 2
1
2
D
DELAY τ1
DELAY τ1
11
12
DELAY τ2
DELAY τ2
13
14
EQUALIZATION FILTER 2
EQUALIZATION FILTER 1
22
21
31
32
51
52

FIG. 5B

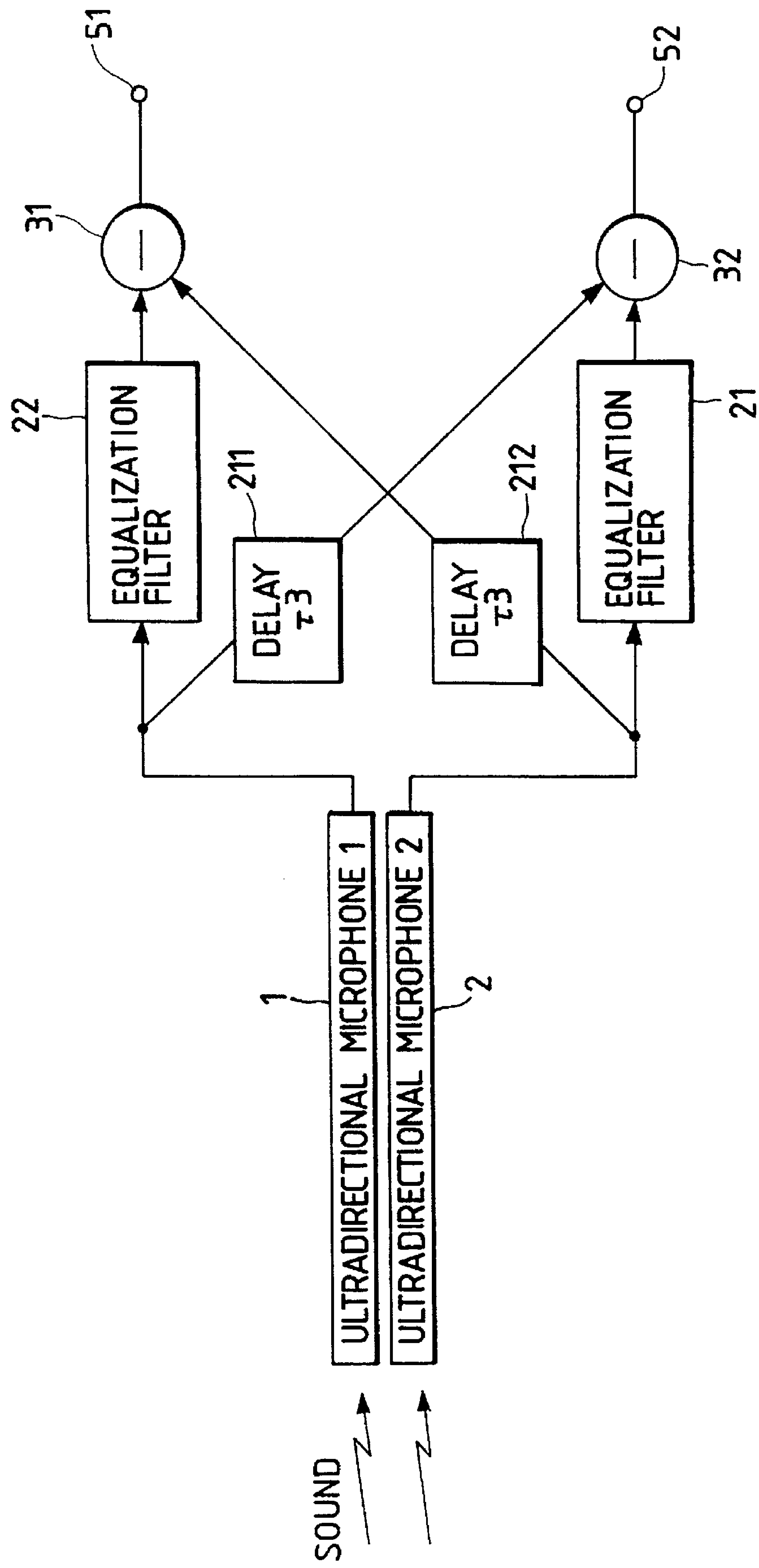

51
52
31
32
22
21
EQUALIZATION FILTER
EQUALIZATION FILTER
211
212
DELAY τ3
DELAY τ3
ULTRADIRECTIONAL MICROPHONE 1
ULTRADIRECTIONAL MICROPHONE 2
1
2
SOUND

FIG. 6

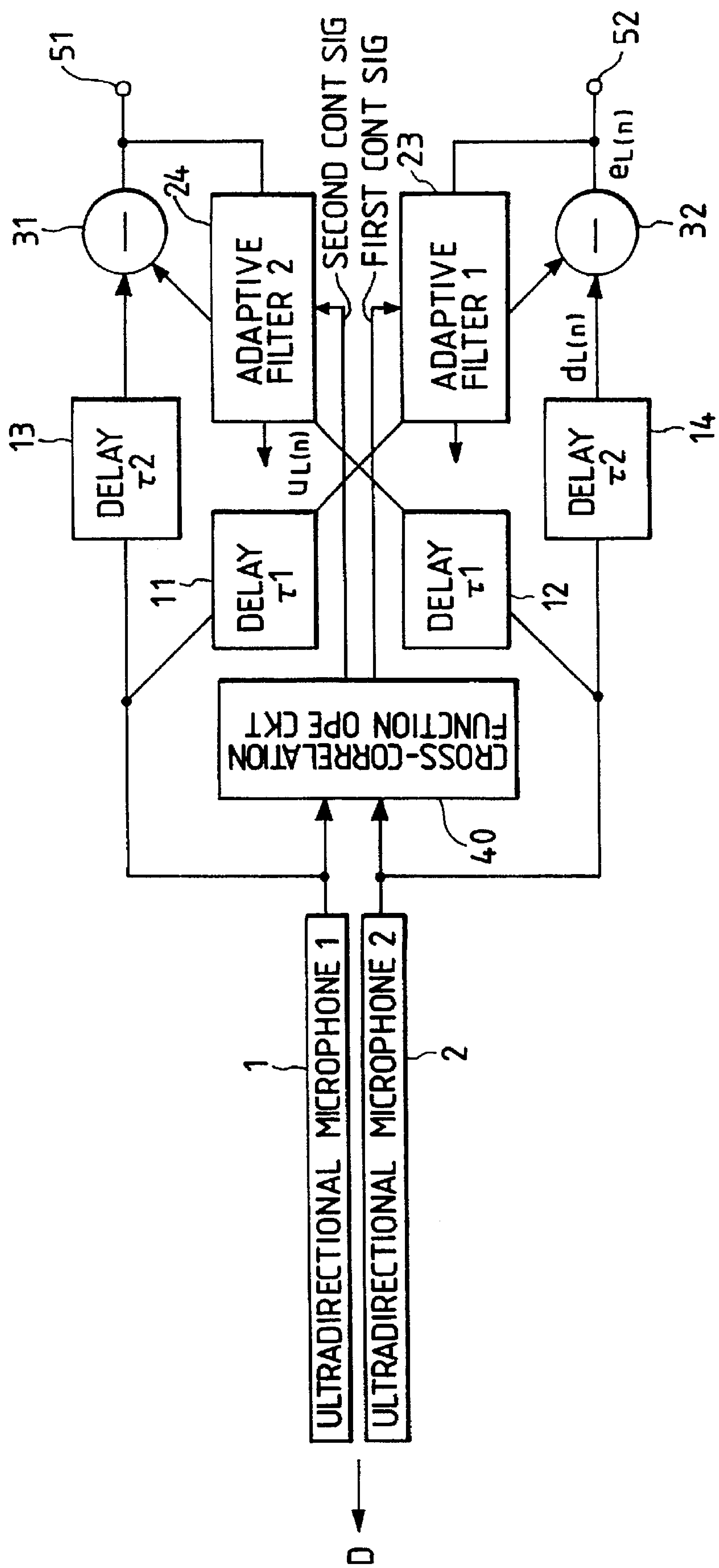
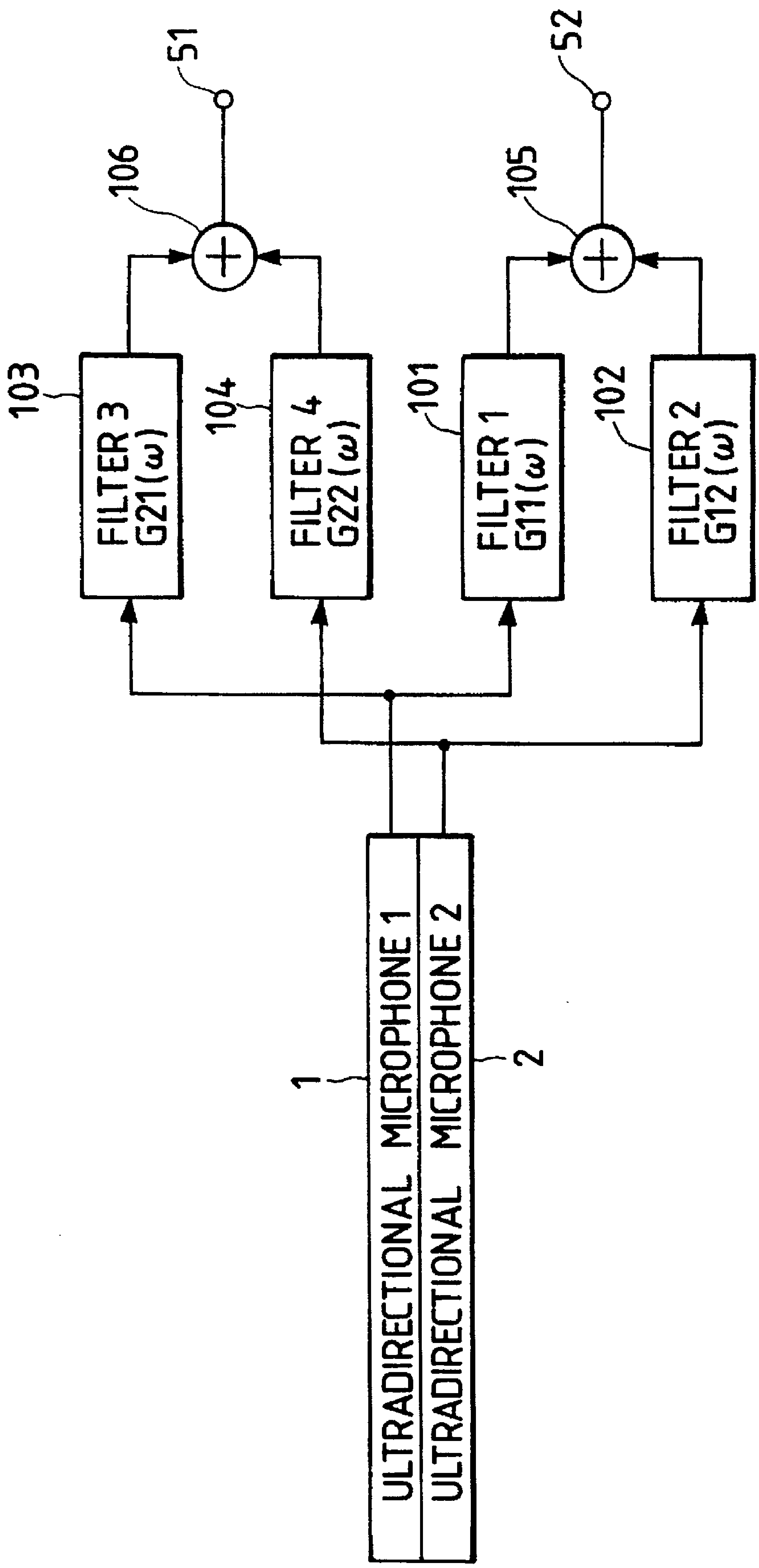

51
52
31
32
24
23
ADAPTIVE FILTER 2
ADAPTIVE FILTER 1
SECOND CONT SIG
FIRST CONT SIG
$e_L(n)$
$d_L(n)$
$u_L(n)$
13
DELAY $\tau 2$
14
DELAY $\tau 2$
11
DELAY $\tau 1$
12
DELAY $\tau 1$
CROSS-CORRELATION FUNCTION OPE CKT
40
1
ULTRADIRECTIONAL MICROPHONE 1
2
ULTRADIRECTIONAL MICROPHONE 2
D

FIG. 7


51
52
106
105
103
FILTER 3
G21(ω)
104
FILTER 4
G22(ω)
101
FILTER 1
G11(ω)
102
FILTER 2
G12(ω)
1
ULTRADIRECTIONAL MICROPHONE 1
ULTRADIRECTIONAL MICROPHONE 2
2

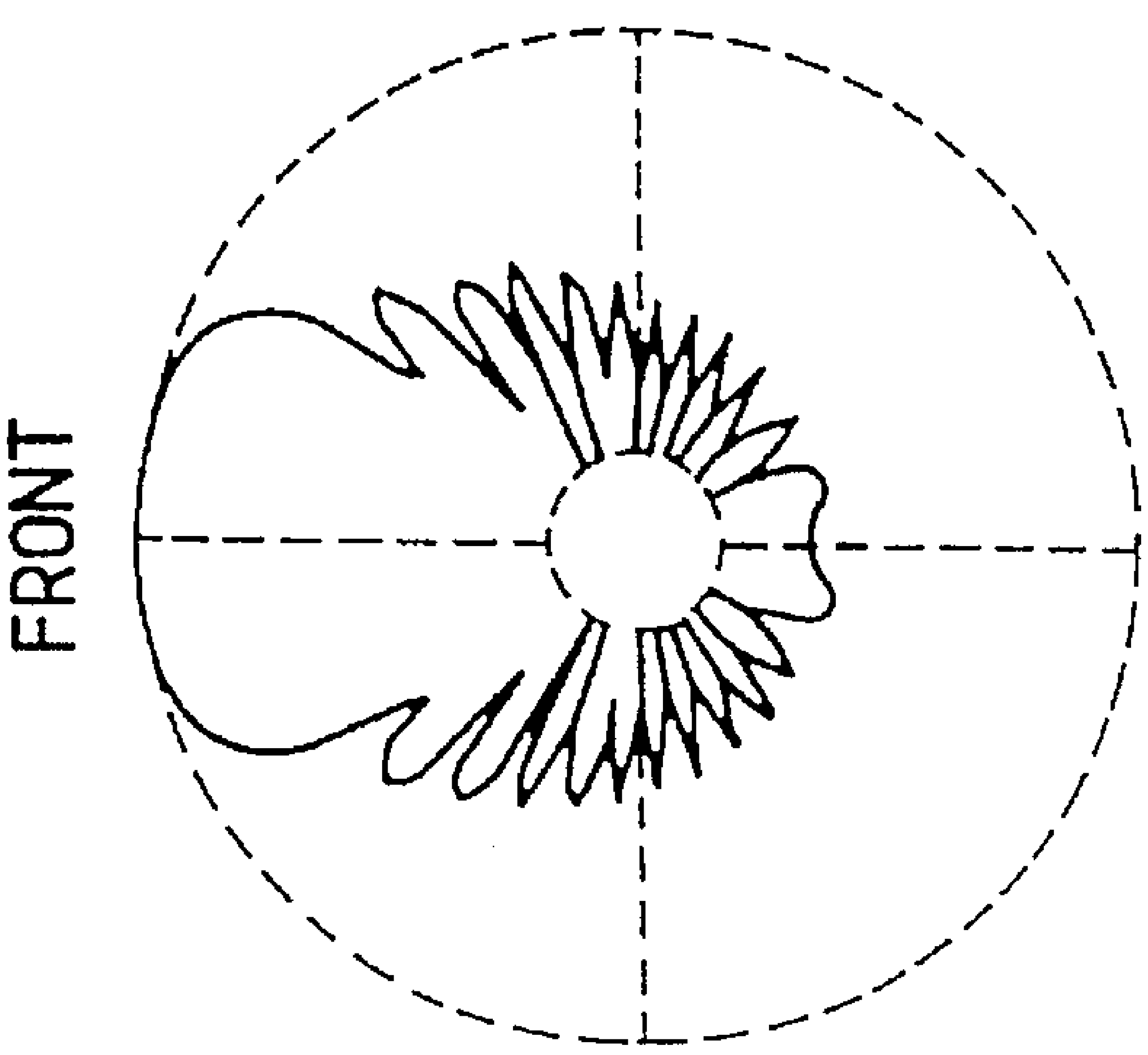

FRONT

FIG. 8

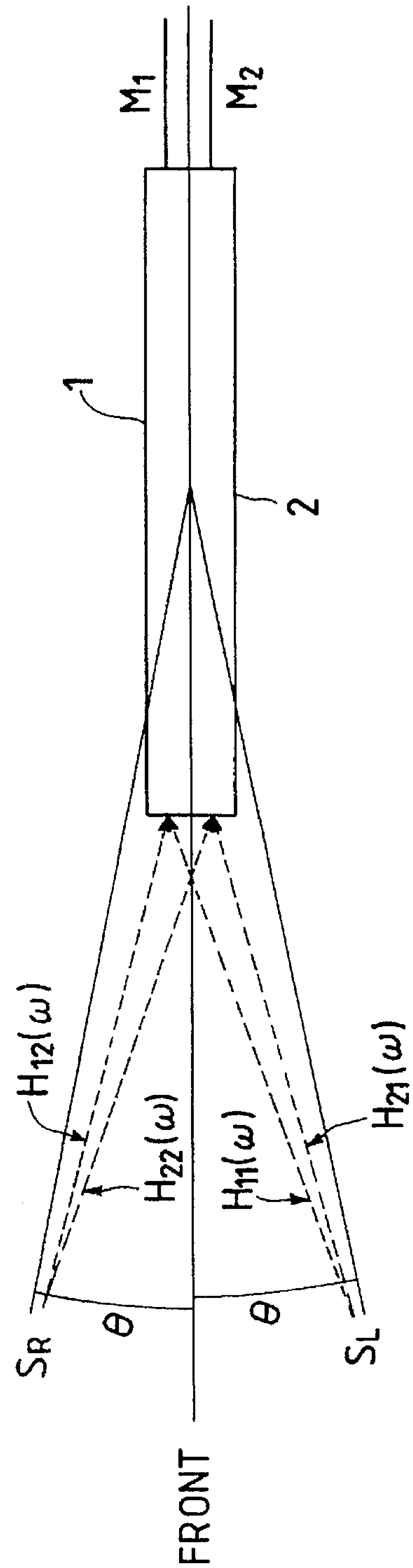

M1
M2
1
2
$H_{12}(\omega)$
$H_{22}(\omega)$
$H_{11}(\omega)$
$H_{21}(\omega)$
S_R
θ
θ
S_L
FRONT

FIG. 9

FIG. 10A

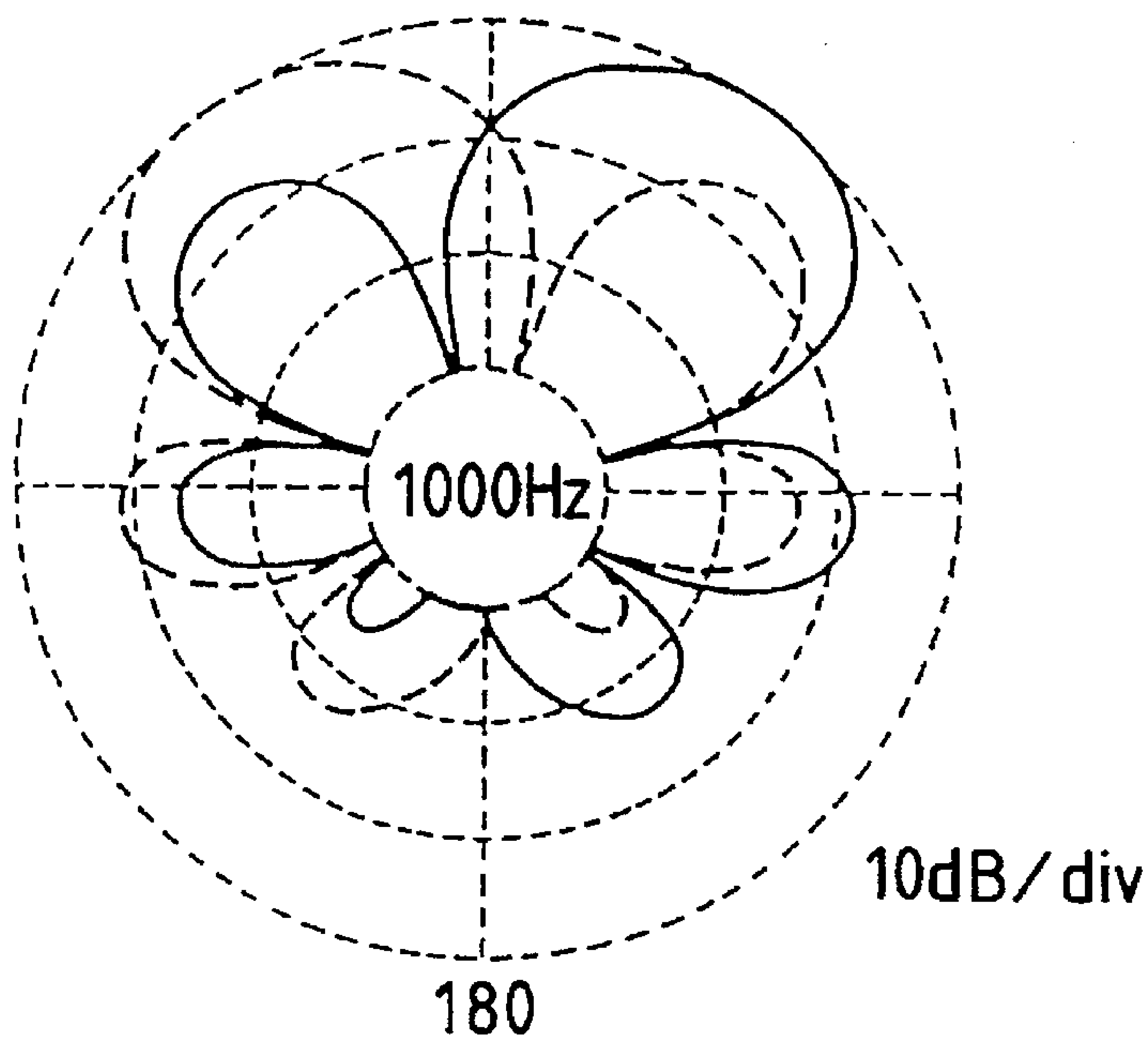
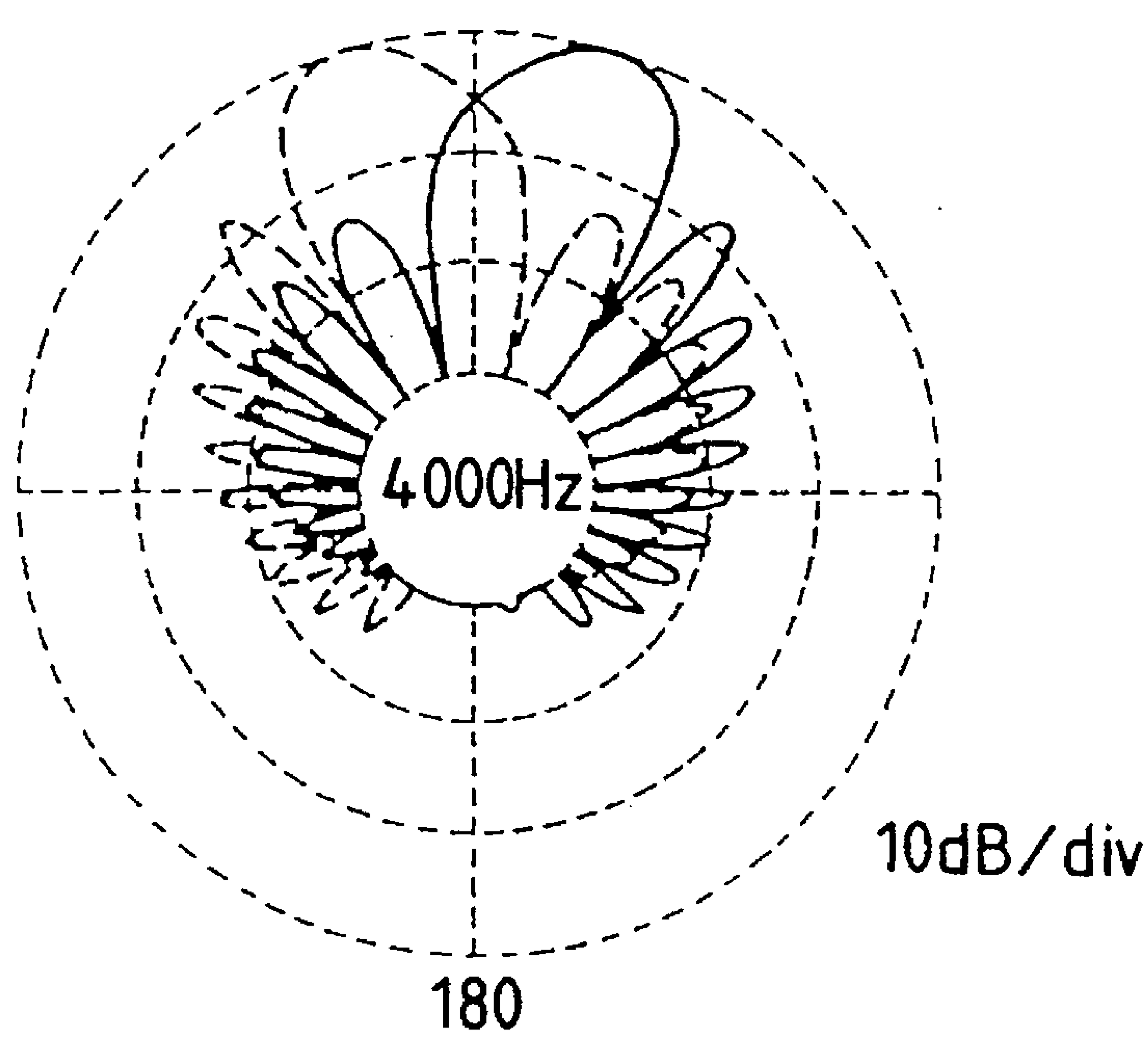


FIG. 10B



STEREO ULTRADIRECTIONAL MICROPHONE APPARATUS

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to a stereo ultradirectional microphone apparatus for receiving and converting a sound into a set of stereo sound signals.

2. Description of the Prior Art

Sets of stereo microphones are known. As a simple, a set of stereo microphones comprising two directional microphones are used. Each of these directional microphones has a unidirectional characteristic showing a high sensitivity in a direction (hereinafter this direction in which the microphone shows a high sensitivity is referred to as a main lobe). Two directional microphones are arranged to obtain a stereo effect such that a lobe of one directional microphone is directed to +θ direction and a lobe of the other directional microphone is directed to −θ direction with respect to the front thereof wherein θ is selected from the range $45° \leqq |\theta| \leqq 90°$. Such general type stereo microphones aim to record sounds from sources existing in a wide angle range viewed from the recording point, i.e., a location of the stereo microphones. However, if a sound from a source existing a predetermined narrow angle range is recorded using general type of stereo microphones, it is impossible to record the sound with a sufficient SN ratio because such stereo microphones have too large width of the main lobe, so that sounds coming from directions other than the predetermined narrow angle rage are recorded as noises. In the actual recording scene, such situations may occur frequently. As a solution to this problem, in place of the unidirectional microphone, an ultradirectional microphone having a more sharp directional characteristics is studied to be applied to the directional microphone apparatus (GERLACH H, "Stereo sound recording with shotgun microphones", J Audio Eng Soc, Vol. 37 No. 10 Page 832–838 '89). This document discloses examples of a stereo recording apparatus to which the ultradirectional microphones is applied, namely, XY and MS structures. The XY structure has two ultradirectional microphones are used where one is directed in +θ direction and the other is directed in −θ direction with respect to the front thereof on recording.

The MS structure has one ultradirectional microphone and a hi-directional microphone wherein a main lobe of the ultradirectional microphone is directed to the front and the lobe of the hi-directional microphone is directed to have an angle of 90° from the front. Left side and right side outputs are obtained by adding or subtracting between the outputs of these two microphones. Both XY and MS structures provide the recording of a sound from a source existing in the more narrow angle range than the general stereo microphones. That is, these structures provide the stereo recording of a sound from a more remote sound source because there is a tendency that unnecessary sounds are not mixed with the necessary sound. In other words, assuming the distances between the sound source and the microphones are the same, these structure provide the stereo recording with a higher SN ratio. However, the document reports problems as follows:

In the XY structure, a sound having a high frequency from a sound source existing at left or right side with respect to the microphones is left and the sound existing at the center is suppressed. Contrary, in the MS structure, the higher frequency of a sound, the more the stereo feeling is lost.

SUMMARY OF THE INVENTION

The present invention has been developed in order to remove the above-described drawbacks inherent to the conventional stereo ultradirectional microphone apparatus.

According to the present invention there is provided a first stereo ultradirectional microphone apparatus for detecting a sound to produce stereo sound signals, comprising: a first ultradirectional microphone, having a first unidirectional characteristic, for detecting and converting the sound into a first sound signal, the first unidirectional characteristic showing a first main lobe having a first axis; a second ultradirectional microphone, having a second unidirectional characteristic which is substantially the same as the first ultradirectional microphone, for detecting and converting the sound into a second sound signal, the second unidirectional characteristic showing a second main lobe having a second axis; the first and second ultradirectional microphones being arranged side by side with a predetermined distance therebetween such that the first main lobe is directed in the same direction as the second main lobe and the first axis is in parallel to the second axis substantially; a first delay circuit for delaying the first sound signal by a delay time; a second delay circuit for delaying the second sound signal by the delay time; a first subtracting circuit for effecting subtraction between an output of the second delay circuit and the output of the first sound signal; and a second subtracting circuit for effecting subtraction between an output of the first delay circuit and the second sound signal, the first and second subtracting circuits producing the stereo sound signals. The ultradirectional microphone has a distance factor more than 1.7 or a directivity index less than 0.34. The delay time may be changed. Favorably, a distance factor is more than 2 and a directivity index I is less than 0.25. More favorably, a distance factor is more than 2.2 and a directivity index I is less than 0.20.

According to the present invention there is also provided a second stereo ultradirectional microphone apparatus for detecting a sound to produce stereo sound signals, comprising: a first ultradirectional microphone, having a first unidirectional characteristic, for detecting and converting the sound into a first sound signal, the first unidirectional characteristic showing a first main lobe having a first axis; a second ultradirectional microphone, having a second unidirectional characteristic which is substantially the same as the first ultradirectional microphone, for detecting and converting the sound into a second sound signal, the second unidirectional characteristic showing a second main lobe having a second axis; the first and second ultradirectional microphones being arranged side by side with a predetermined distance therebetween such that the first main lobe is directed in the same direction as the second main lobe and the first axis is in parallel to the second axis substantially; a first equalizing circuit for frequency-equalizing the first sound signal; a second equalizing circuit for frequency-equalizing the second sound signal; a first delay circuit for providing a delay time to an output of the second equalizing circuit against the first sound signal; a second delay circuit for providing the delay time to an output of the first equalizing circuit against the first sound signal; a first subtracting circuit for effecting subtraction between the output of the second equalizing circuit and the first sound signal; and a second subtracting circuit for effecting subtraction between the output of the first equalizing circuit and the second sound signal, the first and second subtracting circuit producing the stereo sound signals. There are various modification in the locations of the delay circuit and the equalizing circuit.

According to the present invention there is further provided a third stereo ultradirectional microphone apparatus for detecting a sound to produce stereo sound signals, comprising: a first ultradirectional microphone, having a first unidirectional characteristic, for detecting and converting the sound into a first sound signal, the first unidirectional characteristic having a first axis; a second ultradirectional microphone, having a second unidirectional characteristic which is substantially the same as the first ultradirectional microphone, for detecting and converting the sound into a second sound signal, the second unidirectional characteristic having a second axis; the first and second ultradirectional microphones being arranged side by side with a predetermined distance therebetween such that the first axis is directed in the same direction D in parallel to the second axis substantially; a first adaptive filter circuit responsive to a first control signal for adaptively frequency-equalizing the first sound signal; a second adaptive filter circuit responsive to a second control signal for adaptively frequency-equalizing the second sound signal; a first delay circuit for providing a delay time to an output of the second adaptive filter circuit against the first sound signal; a second delay circuit for providing the delay time to an output of the first adaptive filter circuit against the first sound signal; a first subtracting circuit for effecting subtraction between the output of the second adaptive filter circuit and the first sound signal; and a second subtracting circuit for effecting subtraction between the output of the first adaptive filter circuit and the second sound signal; a cross-correlation function operation circuit for operating cross-correlation between the first and second sound signals to detects that the cross-correlations in a first direction making a clockwise angle θ from the direction D and in a second direction making a counterclockwise angle θ from the direction D are larger than a predetermined value respectively, the cross-correlation function operation circuit supplying the first and second control signals when the cross-correlation in the first and second directions are larger than the predetermined value respectively.

According to the present invention there is further provided a fourth stereo ultradirectional microphone apparatus for detecting a sound to produce first and second stereo sound signals, comprising: a first ultradirectional microphone, having a first unidirectional characteristic, for detecting and converting the sound into a first sound signal, the first unidirectional characteristic having a first axis; a second ultradirectional microphone, having a second unidirectional characteristic which is substantially the same as the first ultradirectional microphone, for detecting and converting the sound into a second sound signal, the second unidirectional characteristic having a second axis; the first and second ultradirectional microphones being arranged side by side with a predetermined distance therebetween such that the first axis is directed in the same direction D in parallel to the second axis substantially; a first filter, having a first transfer characteristic, for frequency equalizing the first sound signal; a second filter, having a second transfer characteristic, for frequency equalizing the second sound signal; a first summing circuit for summing outputs of the first and second filters to supply the first stereo signal; a third filter, having a third transfer characteristic, for frequency equalizing the first sound signal; a fourth filter, having a fourth transfere characteristic, for frequency equalizing the second sound signal; and a second summing circuit for summing outputs of the third and fourth filters to supply the second stereo signal, the first to fourth transfere characteristics being determined such that a first sensitivity in the first stereo signal in a first direction making a clockwise angle from the first axis is minimized and a second sensitivity in the second stereo signal in a second direction making a counter clockwise angle from the direction D is minimized.

According to the present invention there is further provided a fifth stereo ultradirectional microphone apparatus as described in the fourth stereo ultradirectional microphone apparatus, wherein it is assumed that the first to fourth transfere characteristics are G11(ω), G12(ω), G21(ω), and G22(ω) respectively and the first ultradirectional microphone has first and second sound pressure frequency characteristics in the first and second directions are H11(ω) and H12(ω) respectively, and the second ultradirectional microphone has third and fourth sound pressure frequency characteristics in the first and second directions are H21(ω) and H12(ω) respectively, the G11(ω) to G22(ω) and H11(ω) and H21(ω) are given by:

$$\begin{cases} G_{11}(\omega) = H_{22}(\omega)/(H_{11}(\omega)H_{22}(\omega) - H_{12}(\omega)H_{21}(\omega) \\ G_{12}(\omega) = -H_{12}(\omega)/(H_{11}(\omega)H_{22}(\omega) - H_{12}(\omega)H_{21}(\omega) \\ G_{21}(\omega) = -H_{21}(\omega)/(H_{11}(\omega)H_{22}(\omega) - H_{12}(\omega)H_{21}(\omega) \\ G_{22}(\omega) = H_{11}(\omega)/(H_{11}(\omega)H_{22}(\omega) - H_{12}(\omega)H_{21}(\omega). \end{cases}$$

BRIEF DESCRIPTION OF THE DRAWINGS

The object and features of the present invention will become more readily apparent from the following detailed description taken in conjunction with the accompanying drawings in which:

FIG. **1** is a bock diagram of a first embodiment of a stereo ultradirectional microphone apparatus of this invention;

FIG. **2** is a plan view of first to fourth embodiments for showing a relation between the first and second ultradirectional microphones;

FIGS. **3**A to **3**E show directional characteristics of output signals of respect portions of the ultradirectional apparatus of the first embodiment;

FIG. **4**A is a plan view of the first embodiment for showing an example of arrangement of the ultradirectional microphones;

FIG. **4**B is a plan view of the first modification of the first embodiment;

FIG. **4**C is a block diagram of a second modification of the first embodiment;

FIG. **4**D is a block diagram of an example of the signal delay circuit of the second modification of the first embodiment;

FIG. **4**E is a block diagram of another example of the signal delay circuit of the second modification of the first embodiment;

FIG. **5**A is a block diagram of a second embodiment showing a structure of the stereo ultradirectional microphone apparatus of the second embodiment;

FIG. **5**B is a block diagram of a modification of the second embodiment;

FIG. **6** is a block diagram of a third embodiment of the stereo ultradirectional microphone apparatus;

FIG. **7** is a bock diagram of a fourth embodiment of a stereo ultradirectional microphone apparatus;

FIG. **8** is an illustration of the fourth embodiment for showing directivities of ultradirectional microphones;

FIG. **9** is an illustration of the fourth embodiment for showing a positional relation between two sound sources and the main lobes of the first and second ultradirectional microphones;

FIG. 10A shows a directivity of the fourth embodiment of the ultradirectional microphone apparatus at 1000 Hz; and

FIG. 10B shows a directivity of the fourth embodiment of the ultradirectional microphone apparatus at 4000 Hz.

The same or corresponding elements or parts are designated as like references throughout the drawings.

DETAILED DESCRIPTION OF THE INVENTION

Hereinbelow will be described a first embodiment of this invention with reference to drawings. FIG. 1 is a bock diagram of the first embodiment for showing a structure of a stereo ultradirectional microphone apparatus of this invention. In FIG. 1, numeral **1** is a first ultradirectional microphone, having a main lobe directing in the longitudinal direction thereof, that is, in the front direction thereof, for receiving a sound, and numeral **2** is a second ultradirectional microphone, having the same structure as the first ultradirectional microphone **1**, arranged on the left side of the first ultradirectional microphone **1** with respect to the front in parallel to the first ultradirectional microphone **1** to have the same distance from a sound source existing in front thereof. Numeral **11** is a first signal delay circuit for delaying an output signal from the first ultradirectional microphone **1**. Numeral **12** is a second signal delay circuit for delaying an output signal from the second ultradirectional microphone **2**. Numeral **31** is a first signal subtracting circuit for effecting subtraction between the output signal from the first ultradirectional microphone i and an output signal from the second signal delay circuit **12**. Numeral **32** is a second signal subtracting circuit for effecting subtraction between the output signal from the second ultradirectional microphone **2** and an output signal from the first signal delay circuit **11**. Numeral **51** is an first output terminal for supplying the output signal from the first subtracting circuit **31**. Numeral **52** is a second output terminal for supplying the output signal from the second subtracting circuit **32**.

The ultradirectional microphone **1** or **2** has not been strictly defined in the general meaning. However, it is said that the ultradirectional microphone has a sharp directivity such as a secondary sound pressure gradient type microphone or more. In other words, the ultradirctional microphone has directivity more than the hypercardioid directional microphone. As an example of the ultradirectional microphone, there are so-called line microphones or gun microphones. For example, a gun microphone/line microphone MKH 816 manufactured by SENNHEISER, a gun microphone/line microphone MKH 416 manufactured by SENNHEISER, and a gun microphone/line microphone WM-L30 manufactured by MATSUSHITA ELECTRIC INDUSTRIAL CO.,LTD. The gun microphone/line microphone MKH 816 is a typical ultradirectional microphone frequently used in recording studios or broadcasting studios. It has a total length of about 54 cm. The gun microphone/line microphone MKH 416 is shorter than the gun microphone/line microphone MKH 816 and has a width of main lobe sightly larger than the gun microphone/line microphone MKH 816. The gun microphone/line microphone WM-L30 has a directivity corresponding to the gun microphone/line microphone MKH 416. As mentioned above, the ultradirectional microphone has a sharp directivity. However, the ultradirectional microphone is one of the unidirectional microphones. Prabolic microphones are known as the ultradirectional microphone.

In this invention, the ultradirectional microphone has a distance factor F more than 1.7 corresponding to directivity

of the cardiode type microphone or directivity index I less than 0.34. Favorably, the ultradirectional microphone has a distance factor F more than 2.0 corresponding to directivity of the hypercardiode type microphone or directivity index I less than 0.25. More favorably, the ultradirectional microphone has a distance factor F more than 2.2 corresponding to directivity of the second order bidirectional type microphone or directivity index I less than 0.20. The gun microphone/line microphone MKH 816 manufactured by SENNHEISER and th gun microphone/line microphone MKH 416 manufactured by SENNHEISER have distance index F of 2.74 and directivity index I of 0.133. Moreover, a cardioid, hypercardiod, second order bidirectional type having a pressure gradient microphoone may be used.

Operation of the stereo ultradirectional microphone apparatus of the first embodiment will be described with reference to FIGS. 1, 2, and 3. FIG. 2 is a plan view for showing a relation between the first and second ultradirectional microphones **1** and **2** and a sound incoming to the first and second ultradirectional microphones **1** and **2**, which is common to all embodiments of this invention. FIGS. 3A to 3D show directional characteristics of output signals of respect portions of the ultradirectional apparatus of the first embodiment. In FIG. 1, it is assumed that the first ultradirectional microphone **1** has substantially the same directional characteristic (shown in FIG. 3A) as the second ultradirectional microphone **2**. The directional characteristics of the first and second ultradirectional microphones **1** and **2** shown in FIG. 3A show main lobes **61***a* and **61***b* directed in the front direction D with axes AX1 and AX2 respectively. The first and second ultradirectional microphones **1** and **2** are arranged side by side with a distance d therebetween such that the main lobe **61***a* of the first ultradirectional microphone **1** is directed in the same direction as the main lobe **61***b* of the second ultradirectional microphone **2** and the axis AX1 of the main lobe **61***a* is in parallel to the axis AX2 substantially. A sound from a sound source located in the front of the ultradirectional microphones **1** and **2** enters the ultradirectional microphones **1** and **2**. The ultradirectional microphones **1** and **2** convert the sound into electric sound signals respectively. The first signal subtracting circuit **31** operates subtraction between the output signal of the first ultradirectional microphone **1** and a signal obtained by delaying the output signal of the second ultradirectional microphone **2** by τ **1** by the signal delay circuit **12**. As the result, an output signal from the first signal subtracting circuit **31** includes a directional characteristic as shown in FIG. 3B wherein a dead angle **62** is formed in a dead angle direction **63** making a counterclockwise angle $\theta°$ from the front direction D of the ultradirectional microphones **1** and **2** in addition to the directional characteristic as shown by FIG. 3A. The angle θ is given:

$$\theta = \sin^{-1}\left(\frac{\tau 1 \cdot c}{d}\right) \tag{1}$$

where a distance between the first and second ultradirectional microphones **1** and **2** is d and the sound speed is c. More specifically, the distance d is a distance between the acoustic holes **1***a* and **1***b* (mentioned later) of the first and second ultradirectional microphones **1** and **2**. The relation among θ, d, τ **1**, and c is shown in FIG. 2. A sound incoming in a direction making a counterclockwise angle θ from the front of the ultradirectional microphones **1** and **2** reaches the second ultradirectional microphone **2** first and then, reaches the first ultradirectional microphone **1** with a delay time $d \cdot \sin(\theta)/c$. Therefore, a sensitivity in the direction making the counterclockwise angle θ from the front of the ultradirectional microphones **1** and **2** can be reduced to nearly zero by delaying the output signal from the second ultradirectional microphone by $\tau 1 = d \cdot \sin(\theta)/c$ with the signal delay circuit **12** and by subtracting the delayed signal from the output signal from the first ultradirectional microphone **1**. In other words, a dead angle is formed in the direction making the counterclockwise angle θ from the front of the ultradirectional microphones **1** and **2**. This corresponds to the method of forming directional characteristic in the pressure-gradient microphones and the directional characteristic added by this operation is shown by FIG. **3B**. That is, the final directional characteristic of the output signal of the signal subtracting circuit **31** is obtained such that the directional characteristic shown in FIG. **3A** is multiplied with that shown in FIG. **3B**, that is, it is shown as FIG. **3C**. Similarly, the final directional characteristic of the output signal of the signal subtracting circuit **32** is obtained such that the directional characteristic shown in FIG. **3A** is multiplied with that shown in FIG. **3D**, that is, it is shown as FIG. **3E**. Therefore, the combined directional characteristics as shown in FIG. **3C** and **3E** provide stereo recording of a sound from a remote sound source. That is, the output of the first and second subtracting circuits **31** and **32**, i.e., first and second stereo sound signals having first and second directional characteristics showing third and fourth main lobes **64a** and **64b** having third and fourth axes **65a** and **65b** respectively and the delay time is determined by the predetermined distance d and a half of the angle between the third and fourth axes **65a** and **65b**.

A first modification of the first embodiment will be described. FIG. **4A** is a plan view of the first embodiment for showing an example of arrangement of the ultradirectional microphones **1** and **2**. FIG. **4B** is a plan view of the first modification of the first embodiment.

In the first embodiment, each of the ultradirectional microphones **1** and **2** has an acoustic tube **1b** where acoustic holes **1b** are arranged on a side surface of the acoustic tube **1b** in the longitudinal direction of the acoustic tube **1b**. The acoustic holes **1a** respectively allow the sound to enter the acoustic tube **1b** to obtain the ultradirectional characteristic. A microphone unit **1d** having a diaphragm **1c** for receiving the sound is provided to one end of the acoustic tube **1b**. The sound which entered the acoustic tube **1b** is guided by the acoustic tube **1b** and is received by the diaphragm **1c** of the microphone unit **1d**, i.e., a condenser microphone unit. Moreover, the ultradirectional microphones **1** and **2** are arranged such that acoustic holes **1a** of the ultradirectional microphone **1** confront to acoustic holes **2a** of the ultradirectional microphone **2** as shown in FIG. **4A**. On the other hand, as shown in FIG. **4B** in the modification of the first embodiment, the ultradirectional microphones **1** and **2** are arranged such that the acoustic holes **1a** are directed in the opposite direction of acoustic holes **2a** of the ultradirectional microphone **2**. This arrangement is provided in order to maintain the distance d relatively larger to improve a directional characteristic at low frequencies with a compact size of the stereo ultradirectional microphone apparatus. That is, as shown in FIG. **4B**, the size of this stereo ultradirectional microphone apparatus can be miniaturized by that the first and second ultradirectional microphones **1** and **2** are arranged as close as possible.

FIG. **4C** is a block diagram of a second modification of the first embodiment. The basic structure of the second modification of the first embodiment is substantially the same as the first embodiment. The difference between the second modification and the first embodiment is in that delay times of the signal delay circuits **111** and **112** are variable. The variation in the delay time of the signal delay circuit **111** and **112** provides the change of an angle between the main lobes **64a** and **64b** of combined directional characteristics of the first and second stereo signals, that is, the directional characteristics of the output of the signal subtracting circuits **31** and **32**. In other words, the variation in the delay time of the signal delay circuit **111** and **112** provides the change of an angle between the dead angle **62** formed in the directional characteristics of the outputs of the signal subtracting circuits **31** and FIG. **4D** is a block diagram of an example of the signal delay circuit of the second modification of the first embodiment. This example shows a digital type of the signal delay circuit. That is, the signal delay circuit **111a** comprises a shift register circuit having a plurality of shift register elements and a switch circuit for selectively output of either of the shift register element in response to a selection signal externally inputted. This switch may be operated manually using a manually operation switch. The number of stages of the shift registers is determined by the switch circuit and the delay time is determined by this number. FIG. **4E** is a block diagram of another example of the signal delay circuit of the second modification of the first embodiment. This example shows an analog type of the signal delay circuit **111b**. The signal delay circuit **111b** comprises an operational amplifier circuit forming a secondary phase shifter having variable resistors R1 and R2. The resistances of the R1 and R2 are changed to vary the delay time under the condition that a multiplication between resistances of R1 and R2 is constant.

As described above, the second modification of the first embodiment, change in the delay times τ **1** of the first and second signal delay circuits provides a change the direction of the dead angle **62** represented by angle θ. In this condition, $0 < \tau 1 \leqq d/c$ when $0° < \theta \leqq 90°$.

Hereinbelow will be described a second embodiment of a stereo ultradirectional microphone apparatus of this invention with reference to drawings. FIG. **5A** is a block diagram of the second embodiment showing a structure of the stereo ultradirectional microphone apparatus. In FIG. **5A**, numeral **1** is a first ultradirectional microphone, and numeral **2** is a second ultradirectional microphone arranged on the left side of the first ultradirectional microphone **1** with respect to the front thereof in parallel to the first ultradirectional microphone **1** to have the same distance from a sound source existing in Front thereof. Numeral **11** is a first signal delay circuit for delaying an output signal from the first ultradirectional microphone **1**. Numeral **12** is a second signal delay circuit for delaying an output signal from the second ultradirectional microphone **1**. Numeral **13** is a third signal delay circuit for delaying an output signal from the first ultradirectional microphone **1**. Numeral **14** is a fourth signal delay circuit for delaying an output signal from the second ultradirectional microphone **1**. Numeral **21** is a first equalization Filter for frequency-equalizing an output signal from the first signal delay circuit **11**. Numeral **22** is a second equalization Filter for frequency-equalizing an output signal from the second signal delay circuit **12**. Numeral **31** is a first signal subtracting circuit for effecting subtraction between the output signal of the second equalization filter **22** and an output signal from the third signal delay circuit Numeral **32** is a second signal subtracting circuit for effecting subtraction between the output signal of the first equalization filter **21** and an output signal from the fourth signal delay circuit **14**. Numeral **51** is an first output terminal for supplying the output signal from the subtracting circuit **31**. Numeral **52** is a second output terminal for supplying the output signal from the subtracting circuit **31**.

Operation of the stereo ultradirectional microphone apparatus structured as mentioned above will be described. In

FIG. 5A, the difference between this embodiment and the first embodiment is in that the third signal delay circuit **13** is provided between the first ultradirectional microphone **1** and the first signal subtracting circuit **31**, the fourth signal delay circuit **14** is provided between the second ultradirectional microphone **2** and the second signal subtracting circuit **32**, the first equalization filter **21** is provided between the first signal delay circuit **11** and the second signal subtracting circuit **32**, and the second equalization filter **22** is provided between the second signal delay circuit **12** and the first signal subtracting circuit **31**. These added equalization filters **11** and **22** are provided for equalizing in the amplitude phase characteristics between the first and second ultradirectional microphones **1** and **2**. That is, generally, there is a dispersion between the ultradirectional microphones **1** and **2** in the amplitude phase characteristic. Therefore, these additional circuits are provided to accurately equalize the amplitude phase characteristic of the first and second ultradirectional microphones **1** and **2** and cancel the resultant sound signals obtained by the first and second signal subtracting circuit **31** and **32** respectively when the sounds are incoming from sound sources existing in the dead angles. In connection with determination of transfer characteristics of the first and second equalization filters **21** and **22**, assuming that sound pressure frequency characteristics of the first and second ultradirectional microphones **1** and **2** with respect to the direction providing a clockwise angle θ° are $M1_R(\omega)$ and $M2_R(\omega)$ respectively, the transfer characteristic $H1(\omega)$ of the first equalization filter **21** is determined by:

$$H1(\omega)=\frac{M2_R(\omega)}{M1_R(\omega)} \tag{2}$$

The output of the first ultradirectional microphone **1** with respect to the sound incoming from a direction providing the clockwise angle θ is delayed by a delay time τ **1** by the first signal delay circuit **11** and then the delayed signal is multiplied by the characteristic represented by Eq. (2) by the first equalization filter **21** to equalizes the delayed signal to have the sound pressure characteristic of the second ultradirectional microphone **2** with respect to the direction providing the clockwise angle θ°. The equalized signal is subtracted from the output of the fourth signal delay circuit **14** by the second signal subtracting circuit **32** to cancel the sound signal of the sound incoming from the direction providing the clockwise angle θ°. Here, the fourth signal delay circuit **14** is provided to effect a compensation for the signal delay in the first equalization filter **21**. Similarly, the transfere characteristic $H2(\omega)$ of the first equalization filter **22** is determined by:

$$H2(\omega)=\frac{M1_L(\omega)}{M2_L(\omega)} \tag{3}$$

where $M1_L(\omega)$ and $M2_L(\omega)$ are sound pressure frequency characteristics of the first and second ultradirectional microphones **1** and **2** with respect to the direction providing a counterclockwise angle θ° from the front direction D.

The output of the second ultradirectional microphone **2** with respect to the sound incoming from a direction providing the counterclockwise angle θ° is delayed by a delay time τ **1** by the second signal delay circuit **12** and then, the delayed signal is multiplied by the characteristic represented by Eq. (3) by the second equalization filter **22** to equalize the delayed signal to have the sound pressure characteristic of the first ultradirectional microphone **2** with respect to the direction providing the counterclockwise angle θ°. The equalized signal is subtracted from the output of the third signal delay circuit **13** by the first signal subtracting circuit **31** to cancel the sound signal of the sound incoming from the direction providing the counterclockwise angle θ°. Here, the third signal delay circuit **13** is provided to effect a compensation for the signal delay in the second equalization filter **22**.

As mentioned above, in the second embodiment, if there is a dispersion in the frequency characteristic or the like, between the first and second ultradirectional microphones **1** and **2**, the dead angles in the directions providing clockwise and counterclockwise angle from the front of the first and second ultradirectional microphones **1** and **2** are accurately formed. Therefore, favourable directivities of stereo ultradirectional microphone apparatus are provided.

In this embodiment, the difference between the delay of the delay **13** and the total delay time of the signal delay circuit **12** and the equalization filter **22** corresponds to d·sine (θ). Therefore, the signal delay circuit **11** and **12** can be omitted case by case. For example, if the equalization filter **22** has a delay time of d·sine(θ), the

FIG. **5B** is a block diagram of a first modification of the second embodiment. The basic structure of this first modification is substantially the same as the second embodiment. The difference between this modification of the second embodiment and the second embodiment is in that the equalization filter **21** is provided between a junction point between the ultradirectional microphone **2** and the delay circuit **212** and the subtracting circuit **32**. Moreover, the equalization filter **22** is provided between a junction point between the ultradirectional microphone **1** the delay circuit **211** and the subtracting circuit **31**. Further, the delay circuits **13** and **14** are omitted and delay circuits **211** and **212** has a delay time τ **3**.

An output of the first ultradirectional microphone **1** is delayed by the delay circuit **211**. An output of the second ultradirectional microphone **1** is frequency-equalized by the equalization filter **21**. The subtracting circuit **32** subtracts the output of the delay circuit **211** from the output of the equalization filter **21**. Similarly, the output of the second ultradirectional microphone **2** is delayed by the delay circuit **212**. The output of the first ultradirectional microphone **1** is frequency-equalized by the equalization filter **22**. The subtracting circuit **31** subtracts the output of the delay circuit **212** from the output of the equalization filter **22**. The outputs of the subtracting circuits **31** and **32** provide stereo signals. The delay time τ **3** corresponds to a total of the delay time τ **1** and the delay time of the equalization filter **21** or **22**.

As mentioned above, only one modification of the second embodiments is described. However, there are many modifications of the second embodiment can be considered with respect to locations of the equalizing filters and delay circuits.

Hereinbelow will be described a third embodiment of a stereo ultradirectional microphone apparatus of this invention with reference to drawings. FIG. **6** is a block diagram of the third embodiment showing a structure of the stereo ultradirectional microphone apparatus of the third embodiment. In FIG. **6**, the first ultradirectional microphone **1**, the second ultradirectional microphone **2**, the first signal delay circuit **11**, the second signal delay circuit **12**, the third signal delay circuit **13**, the fourth signal delay circuit **14**, the first and second signal subtracting circuit **31** and **32**, and the first and second output terminals **51** and **52** have the same structure as the second embodiment respectively. The difference between the second and third embodiment in the structure is as follows: Numeral **40** is a cross-correlation function operation circuit for operating cross-correlation function in response to the output signals of the first and second ultradirectional microphones **1** and **2**. Numeral **23** is a first adaptive filter **23** which is replaced with the equalization filter **21** of the second embodiment. The first adaptive filter **23** effects the frequency equalizing of the output signal of the first signal delay circuit **11** with a transfer characteristic adaptively renewed on the basis of the output of the second signal subtracting circuit **32** in response to a first control signal, i.e., an output of the cross-correlation function operation circuit **40** to supply its output to the second signal subtracting circuit **32**. Numeral **24** is a second adaptive filter which is replaced with the equalization filter **22** of the second embodiment. The second adaptive filter **24** effects the frequency equalizing of the output signal of the second signal delay circuit **12** with a transfer characteristic adaptively renewed on the basis of the output of the first signal subtracting circuit **31** in response to a second control signal, i.e., an output of the cross-correlation function operation circuit **40** to supply its output to the first signal subtracting circuit **31**. In FIG. **6**, leftward arrows (in this drawing) attached to blocks **23** and **24** denote that these blocks are the adaptive filters.

Operation of the stereo microphone of the third embodiment will be described with reference to FIG. **6**. In FIG. **6**, the difference in operation between the third embodiment and the second embodiment is in that the first and second adaptive filters **23** and **24** adaptively equalize the dispersion in frequency characteristic with respect to the sound incoming in the dead angle directions (±θ°) between the first and second ultradirectional microphones **1** and **2**. Here, as an example of the first and second adaptive filters **23** and **24**, an adaptive equalizer will be described which employs the normalized LMS algorithm (which is disclosed, for example, in J. I. Nagumo and A. Noda, "A Learning Method for System Identification", IEEE Trans. Automatic Control, vol. AC-12, pp. 282–287, Jun. 1967, or A. E. Albert and L. S. Gardner, Jr., "Stochastic Approximation and Nonlinear Regression", (MIT Press, 1967)).

Assuming that an impulse response (filter coefficient) providing a transfer characteristic of the first adaptive filter **23** is $h_L(n)$, the output of the first signal delay circuit **11** is $u_L(n)$, the output of the fourth signal delay circuit **14** is $d_L(n)$, and the output of the second signal subtracting circuit **32** is $e_L(n)$, the normalized LMS algorithm is represented by Eqs. (4) and (5).

$$h_L(n+1)=h_L(n)+\frac{\alpha}{\|u_L(n)\|^2}\,u_L(n)e_L(n) \tag{4}$$

$$e_L(n)=d_L(n)-u_L^T(n)h_L(n) \tag{5}$$

The first adaptive filter **23** renews the filter coefficients represented by Eq. (4) and effects an operation of the second term on the right side of Eq. (5). The sine of "–" on the right side of Eq. (5) corresponds to the operation of the second signal subtracting circuit **32**. If $u_L(n)$ and $d_L(n)$ are independent each other, the Eq. (4) cannot converge. Therefore, in order to operate the adaptive filter normal, it is necessary to renew the filter coefficient represented by Eq. (4) only when a sound incoming from the dead angle direction has larger intensity. Accordingly, the cross-correlation function operation circuit **40** detects whether or not correlation with respect to a sound incoming in the direction providing the clockwise angle θ° from the front of the ultradirectional microphones **1** and **2** is high to supply the correlation detection signal as the first control signal to the first adaptive filter **23**. In response to this, the first adaptive filter **23** renews the filter coefficient represented by Eq. (4) only when the correlation is high. The fourth signal delay circuit **14** is provided for satisfying the law of cause and effect with respect to time base of respective signals, that is, it delays the output of the ultradirectional microphone **2** with a time delay τ **2** corresponding to a time interval of the filter impulse response $h_L(n)$. According to the structure mentioned above, the filter coefficients $h_L(n)$ is renewed such that $e_L(n)$ becomes close to zero with respect to the sound incoming from the direction providing the clockwise angle θ° from the front of the ultradirectional microphones **1** and **2**. Therefore, a dead angle in the directivity in the direction providing the clockwise angle θ° from the front of the ultradirectional microphones **1** and **2** is clearly formed.

Assuming that an impulse response (filter coefficient) providing a transfer characteristic of the second adaptive filter **24** is $h_R(n)$, the output of the second signal delay circuit **12** is $u_R(n)$, the output of the third signal delay circuit **13** is $d_R(n)$, and the output of the first signal subtracting circuit **31** is $e_R(n)$, the normalized LMS algorithm is represented by Eqs. (6) and (7).

$$h_R(n+1)=h_R(n)+\frac{\alpha}{\|u_R(n)\|^2}\,u_R(n)e_R(n) \tag{6}$$

$$e_R(n)=d_R(n)-u_R^T(n)h_R(n) \tag{7}$$

The second adaptive filter **24** renews the filter coefficients represented by Eq. (6) and effects an operation of the second term on the right side of Eq. (7). The sine of "-" on the right side of Eq. (7) corresponds to the operation of the first signal subtracting circuit **31**. If $d_R(n)$ and $u_R(n)$ are independent each other, the Eq. (6) cannot converge. Therefore, in order to operated the adaptive filter normal, it is necessary to renew the filter coefficient represented by Eq. (6) only when a sound incoming from the dead angle direction has larger intensity. Accordingly, the cross-correlation function operation circuit **40** detects whether or not correlation with respect to a sound incoming in a direction providing the counterclockwise angle θ° from the front of the ultradirectional microphones **1** and **2** is high to supply the correlation detection signal to the second adaptive filter **24**. The second adaptive filter **24** renews the filter coefficient represented by Eq. (6) only when the correlation is high. The third signal delay circuit **13** is provided for that the output of the ultradirectional microphone **1** is delayed in accordance with the delay time occurring in the adaptive filter **24**. That is, the delay time is se to τ **2** corresponding to the filter impulse response $h_R(n)$. According to the structure mentioned above, the filter coefficients $h_R(n)$ is renewed such that $e_R(n)$ becomes close to zero with respect to the sound incoming from the direction providing counterclockwise angle θ° from the front of the ultradirectional microphones **1** and **2**. Therefore, a dead angle in the directivity in the direction providing the counterclockwise angle θ° from the front of the ultradirectional microphones **1** and **2** is clearly formed.

Here, $h_L(n)$ and $h_R(n)$ are vectors representing filter coefficient array at a time n and $u_L(n)$ and $u_L(n)$ are tap input vectors ($u_L(n)=\{u_L(n), u_L(n-1,)\ u_L(n-2), \ldots\}$, and the dimension of respective vector are equal.

As similar to the second embodiment, there are many modifications can be considered with respect to the locations of the delay circuits and the adaptive filters as clearly understood from FIG. **5B**.

Here, the operation of the third embodiment will be described more specifically. In order to form the dead angles mentioned above, it is necessary to effect equalization in the sound pressure frequency characteristic between the ultradirectional microphones i and **2** before the subtraction for forming the dead angle. Generally, there is a slight dispersion in the characteristic between the ultradirectional microphones **1** and **2** due to the manufacturing process. When the signals from the two microphones are cancelled by subtraction, the agreement between these two microphones in the pressure frequency characteristic with respect to directions of the dead angles is necessary. Therefore, the adaptive filters **23** and **24** are provided to effect equalization in the sound pressure sensitivity characteristic characteristic between the ultradirectional microphones **1** and **2**. The adaptive filter **23** has a given filter coefficient h_L in the initial condition. That is, the adaptive filter **23** does not have a filter characteristic for effecting equalization between the ultradirectional microphones **1** and **2** in the initial condition. The adaptive filter **23** renews the filter coefficient in accordance with the result of the Eqs. (4) and (5) obtained on the basis of the error signal e_L, i.e., the output of the signal subtracting circuit **32** in response to the first control signal, that is, the output signal of the cross-correlation function operation circuit **40**. This converges the error signal e_L such that the error signal has a minimum value. The smaller the error signal e_L the smaller the output of the second signal subtracting circuit **32**. In other words, the apparent sensitivity of the ultradirectional microphone **2** in the dead angle decreases in the necessary frequency range. Therefore, the adaptive filter **23** operates as the frequency equalizer by renewing of the filter coefficient, so that signal cancelling is effected accurately.

Here, it is necessary to renew the filter coefficient only when the sound incoming from the desired dead angle direction. In other words, if the renewing is effected when the sound comes from only the front, the dead angle would be formed in the front of the ultradirectional microphones **1** and **2**. This is different from the desired directivity. Therefore, the desired directivity having dead angles in the directions making the clockwise and counter clockwise angles of θ° should be formed. Thus, when the sound comes in the direction of the desired dead angle, the cross-correlation function operation circuit **40** output the first or second control signal. The cross-correlation function operation circuit **40** detects this. That is, in connection with the dead angle making the clockwise angle, the cross-correlation function operation circuit **40** detects whether signal components in the output of the ultradirectional microphones **1** and **2** incoming from the dead angle in the direction making the clockwise angle of θ° from the front have a larger intensity than signal components incoming from the other directions. More specifically, the cross-correlation function operation circuit **40** detects a cross-correlation function $R_{XY}(1)$ from the outputs of the ultradirectional microphones **1** and **2** and detects a degree of the correlation of the sound signal components incoming from the dead angle in the direction making the clockwise angle of θ°. The cross-correlation function R_{XY} is given by:

$$R_{XY}(1)=E\{X(t+1)Y(t)\}$$

where E{} is an expected value.

It is assumed that the output of the ultradirectional microphone **1** is X(t) and the output of ultradirectional microphone **1** is Y(t). The term Y(t) lags the term X(t) with respect to the sound signal incoming in the direction making the clockwise angle θ° has a delay d·sine(θ). Therefore, if $R_{XY}(d\cdot\sin(\theta))>a$, the cross-correlation function operation circuit **40** outputs the first control signal to effect renewing the filter coefficient of the adaptive filter **23** because the correlation of the sound signal incoming from the desired dead angle in the direction making the clockwise angle θ is large. If $R_{XY}(-d\cdot\sin(\theta))>a$, the cross-correlation function operation circuit **40** outputs the second control signal to effect renewing the filter coefficient of the adaptive filter **24** because the correlation of the sound signal incoming from the desired dead angle in the direction making a counter-clockwise angle θ is large. Here d is the distance between the ultradirectional microphones **1** and **2** and a is a predetermined threshold value.

The cross-correlation function operation circuit **40** detects the cross-correlation function with respect to the right and left dead angles at regular time interval and the cross-correlation of the right and left dead angles are large, the first and the second control signals are supplied to the first and second adaptive filter **23** and **24** respectively.

Hereinbelow will be described a fourth embodiment of a stereo ultradirectional microphone of this invention with reference to drawings. FIG. **7** is a block diagram of the fourth embodiment for showing a structure of a stereo ultradirectional microphone apparatus of this invention. In FIG. **7**, numeral **1** is a first ultradirectional microphone, and numeral **2** is a second ultradirectional microphone arranged on the left side of the first ultradirectional microphone **1** with a distance d in parallel to the first ultradirectional microphone **1** to have the same distance from a sound source existing in front thereof. Numeral **101** is a first filter having a transfer characteristic G11 (ω) for filtering the output of the first ultradirectional microphone **1**. Numeral **102** is a second filter having a transfer characteristic **G12**(ω) for filtering the output of the second ultradirectional microphone **2**. Numeral **103** is a third filter having a transfer characteristic **G21**(ω) for filtering the output of the first ultradirectional microphone **1**. Numeral **104** is a fourth filter having a transfer characteristic **G22**(ω) for filtering the output of the second ultradirectional microphone **2**. Numeral **105** is a first signal summing circuit for summing outputs of the first filter **101** and the second filter **102**. Numeral **106** is a second signal summing circuit for summing outputs of the third filter **103** and the fourth filter **104**. Numeral **51** is a first output terminal for supplying an output signal of the second signal summing circuit **106**. Numeral **52** is a second output terminal for supplying an output signal of the first signal summing circuit **105**.

Operation of the stereo ultradirectional microphone apparatus structured as mentioned above will be described with reference to FIGS. **7**, **8**, **9**, and **10**.

In FIG. **7**, an output of the ultradirectional microphone **1** is supplied to a first filter **101** and the third filter **103**. An output of the ultradirectional microphone **2** is supplied to a second filter **102** and the fourth filter **104**. The first filter **101** filters the output of the ultradirectional microphone **1** with a transfer characteristic **G11**(ω). The second filter **102** filters the output of the ultradirectional microphone **2** with a transfer characteristic **G12**(ω). The third filter **103** filters the output of the ultradirectional microphone **1** with a transfer characteristic G21(ω). The fourth filter **104** filters the output of the ultradirectional microphone **2** with a transfer characteristic G22(ω). The first signal summing circuit **105** sums the outputs of the first and second filters **101** and **102** to supply a first stereo signal. The second signal summing circuit **106** sums the outputs of the third and fourth filters **103** and **104** to supply a second stereo signal.

FIG. **8** is an illustration of the fourth embodiment for showing directivities of ultradirectional microphones **1** and **2**. In FIG. **7**, it is assumed that the first ultradirectional microphone **1** has the substantially the same directional characteristic as the second ultradirectional microphone **2** as shown in FIG. **8**. FIG. **9** is an illustration of the fourth embodiment for showing a positional relation between two sound sources S_L and S_R and the main lobes of the first and second ultradirectional microphones **1** and **2**. In FIG. **9**, assuming that the sound source located in the −θ direction (the direction providing clockwise angle θ) with respect to the main lobe is S_R, the sound source located in the +θ direction (the direction providing counterclockwise angle θ)with respect to the main lobe is S_R, a transer characteristic from the S_L to the first ultradirectional microphone **1** is **H11**(ω), a transfer characteristic from the S_R to the first ultradirectional microphone **1** is **H12**(ω),a transfer characteristic from the S_L to the second ultradirectional microphone **1** is **H21**(ω), and a transfer characteristic from the S_R to the second ultradirectional microphone **2** is **H22**(ω), the output **M1** of the first ultradirectional microphone **1** against the sound sources S_L and S_R and the output **M2** of the second ultradirectional microphone **2** against the sound sources S_L and S_R are given by:

$$\begin{pmatrix} M_1(\omega) \\ M_2(\omega) \end{pmatrix} = \begin{pmatrix} H_{11}(\omega) & H_{12}(\omega) \\ H_{21}(\omega) & H_{22}(\omega) \end{pmatrix} \begin{pmatrix} S_L(\omega) \\ S_R(\omega) \end{pmatrix} \tag{8}$$

Here, in order to obtain S_L or S_R from the outputs M1 and M2 of the first and second ultradirectional microphones **1** and **2**, Eq. (8) is solved with respect to S_L and S_R by multiply Eq. (8) by the inverse matrix of the matrix H.

$$\begin{pmatrix} H_{11}(\omega) & H_{12}(\omega) \\ H_{21}(\omega) & H_{22}(\omega) \end{pmatrix}^{-1} \begin{pmatrix} M_1(\omega) \\ M_2(\omega) \end{pmatrix} = \begin{pmatrix} S_L(\omega) \\ S_R(\omega) \end{pmatrix} \tag{9}$$

$$\begin{pmatrix} G_{11}(\omega) & G_{12}(\omega) \\ G_{21}(\omega) & G_{22}(\omega) \end{pmatrix} \begin{pmatrix} M_1(\omega) \\ M_2(\omega) \end{pmatrix} = \begin{pmatrix} S_L(\omega) \\ S_R(\omega) \end{pmatrix}$$

Here, Eq. (9) indicates that S_L and S_R can be obtained by multiplying the outputs M1 and M2 of the first and second ultradirectional microphones **1** and **2** by the matrix G (which is an inverse matrix of the matrix H).

The structure shown in FIG. **7** effects this operation. The transfer characteristics **G11**(ω) to **G22**(ω) of the first to fourth filters shown in FIG. **7** are given by:

$$\left\{ \begin{array}{l} G_{11}(\omega) = H_{22}(\omega)/(H_{11}(\omega)H_{22}(\omega) - H_{12}(\omega)H_{21}(\omega)) \\ G_{12}(\omega) = -H_{12}(\omega)/(H_{11}(\omega)H_{22}(\omega) - H_{12}(\omega)H_{21}(\omega)) \\ G_{21}(\omega) = -H_{21}(\omega)/(H_{11}(\omega)H_{22}(\omega) - H_{12}(\omega)H_{21}(\omega)) \\ G_{22}(\omega) = H_{11}(\omega)/(H_{11}(\omega)H_{22}(\omega) - H_{12}(\omega)H_{21}(\omega)) \end{array} \right. \tag{10}$$

As mentioned above, an output of the signal summing circuit **105** has a sensitivity in the direction of S_L (+θ direction from the main lobe) by the structure shown in FIG. **7**, by the transfer characteristics of the first and second filters **101** and **102**, so that a dead angle is formed in the direction of S_R(−θ direction from the main lobe). On the other hand, an output of the signal summing circuit **106** has a sensitivity in the direction of S_R (−θ direction from the main lobe) by the transfer characteristics of third and fourth filters **103** and **104**, so that a dead angle is formed in the direction of S_L (+θ direction from the main lobe). The value of θ is normally selected from 10° to 45°. The effect of the formation of the dead angle is to minimize the sensitivity of each stereo signal from each other. FIG. **10**A shows a directivity of the fourth embodiment at 1000 Hz where the directivity in the output signal at the output terminal **51** is shown. FIG. **10**B shows a directivity of the fourth embodiment at 4000 Hz where the directivity in the output signal at the output terminal **51** is shown. Solid lines shown in FIG. **10**A represents a directional characteristic of Rch obtained from the first output terminal **51** at 1000 Hz. Solid lines shown in FIG. **10**B represents a directional characteristic of Rch obtained from the first output terminal **51** at 4000 Hz. In this embodiment, the transfer characteristics **H11**(ω) to **H22**(ω) are obtained by measuring sound pressure frequency characteristics of the first and second ultradirectional microphones **1** and **2** in an anechoic chamber. In the measurement, the sound sources are arranged in the directions where dead angles are formed as shown in FIG. **9**. In this embodiment, as similar to the second and third embodiments, the formation of dead angles is obtained accurately though there is a dispersion in the characteristics between the first and second ultradirectional microphones, so that a favorable stereo directional characteristic is provided. Further, in this embodiment, the first to fourth transfer characteristics are determined such that a first sensitivity in a first stereo signal in a first direction making a clockwise angle from a first axis, of a first unidirectional characteristic of a first microphone, is minimized and a second sensitivity in the second stereo signal is minimized in a second direction making a counterclockwise angle from a direction of a second axis in parallel with the first axis.

What is claimed is:

1. A stereo ultradirectional microphone apparatus for detecting a sound to produce first and second stereo sound signals, comprising:

(a) a first ultradirectional microphone, having a first unidirectional characteristic, for detecting and converting said sound into a first sound signal, said first unidirectional characteristic having a first axis;

(b) a second ultradirectional microphone, having a second unidirectional characteristic which is substantially the same as said first ultradirectional microphone, for detecting and converting said sound into a second sound signal, said second unidirectional characteristic having a second axis; said first and second ultradirectional microphones being arranged side by side with a predetermined distance therebetween such that said first axis is directed in the same direction D in parallel to said second axis substantially;

(c) a first filter, having a first transfer characteristic, for frequency equalizing said first sound signal;

(d) a second filter, having a second transfer characteristic, for frequency equalizing said second sound signal;

(e) first summing means for summing outputs of said first and second filters to supply said first stereo signal;

(f) a third filter, having a third transfer characteristic, for frequency equalizing said first sound signal;

(g) a fourth filter, having a fourth transfer function, for frequency equalizing said second sound signal; and

(h) second summing means for summing outputs of said third and fourth filters to supply said second stereo signal, said first to fourth transfer characteristics being determined such that a first sensitivity in said first stereo signal in a first direction making a clockwise angle from said first axis is minimized and a second sensitivity in said second stereo signal in a second direction making a counterclockwise angle from said direction D is minimized.

2. A stereo ultradirectional microphone apparatus as claimed in claim **1**, wherein it is assumed that said first to fourth transfer characteristics are **G11**(ω), **G12**(ω), **G21**(ω), and **G22**(ω) respectively and said first ultradirectional microphone has first and second sound pressure frequency characteristics in said first and second directions are **H11**(ω) and **H12**(ω) respectively, and said second ultradirectional microphone has third and fourth sound pressure frequency characteristics in said first and second directions are **H21**(ω) and **H12**(ω) respectively, said **G11**(ω) to **G22**(ω) and **H11** (ω) and **H21**(ω) are given by:

$$\begin{cases} G_{11}(\omega) = H_{22}(\omega)/(H_{11}(\omega)H_{22}(\omega) - H_{12}(\omega)H_{21}(\omega) \\ G_{12}(\omega) = -H_{12}(\omega)/(H_{11}(\omega)H_{22}(\omega) - H_{12}(\omega)H_{21}(\omega) \\ G_{21}(\omega) = -H_{21}(\omega)/(H_{11}(\omega)H_{22}(\omega) - H_{12}(\omega)H_{21}(\omega) \\ G_{22}(\omega) = H_{11}(\omega)/(H_{11}(\omega)H_{22}(\omega) - H_{12}(\omega)H_{21}(\omega). \end{cases}$$

3. A stereo ultradirectional microphone apparatus as claimed in claim **1**, wherein said first ultradirectional microphone has a distance factor more than 2.0.

4. A stereo ultradirectional microphone apparatus as claimed in claim **1**, wherein said first ultradirectional microphone has a directivity index less than 0.25.

5. A stereo ultradirectional microphone apparatus as claimed in claim **1**, wherein said first ultradirectional microphone has a distance Factor more than 2.2.

6. A stereo ultradirectional microphone apparatus as claimed in claim **1**, wherein said first ultradirectional microphone has a directivity index less than 0.20.

* * * * *